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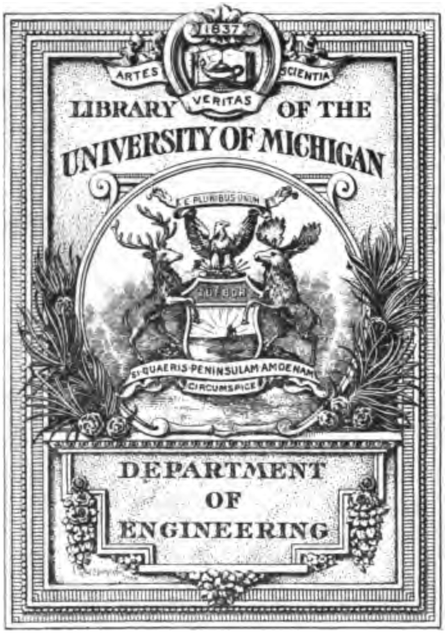
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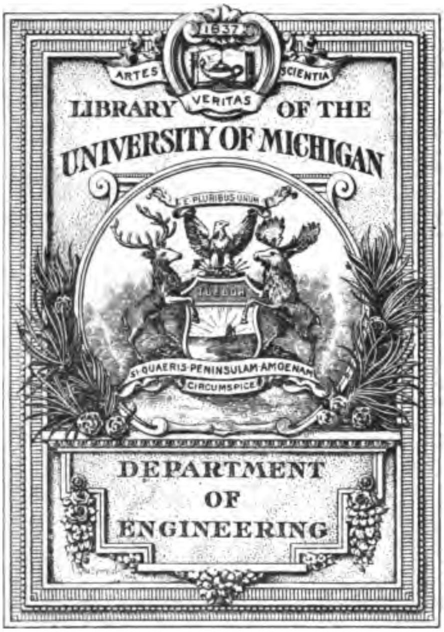

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ETER

THE
WATTHOUR METER

BY

artin
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PREFACE

Considerable information may be derived from various sources relative to the watthour meter. Realizing the desirability and advantage of collecting and publishing such information in concrete form, the authors have endeavored to describe the prominent types and the best usage of modern domestic watthour meters.

It has been the intention to prepare the facts in a form which will impart to the central station manager, the practical meter man and to the student alike, information which will be edifying and serviceable for reference and as a guide for the proper installation, connection, testing and maintenance of that most vital factor in the distributing system—the watthour meter.

Especial attention has been given the induction type and a brief but concise explanation of its theory and operation has been made without the use of higher mathematics. Maintenance and testing are also treated in detail with the dominant idea of giving the practical man assistance in modern, effective and quick methods of obtaining efficient results. Comprehensive tables of testing constants and formula are incorporated in Chapter VIII.

Where specific make of meters is mentioned, such reference should not be construed as indicating the superiority of that particular type over others, but should be considered from the view-point of uniformity of nomenclature in order that comparisons may be made briefly and intelligently.

In preparing the contents of this book, the details of electrical design have been intentionally omitted. The authors did not feel that those interested in the general and practical phases of the subject would desire to go deeply into such matters.

It has been the urgent endeavor to cover the field thoroughly. Supplementary information pertinent to the subject will be gladly furnished by addressing the authors in care of the publishers of this book.

We desire to avail ourselves of the opportunity to thank manufacturers of meters referred to in this publication for their generous and able co-operation. We are also indebted to Mr. F. G. Vaughen, Mr. O. A. Knopp and Mr. F. E. Geibel and others for their liberal advice and assistance.

THE AUTHORS.

San Francisco, June, 1910

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THE WATTHOUR METER

CHAPTER I.

GENERAL.

Definition.

The name "recording wattmeter" or "integrating wattmeter," is often erroneously applied. The true name for the instrument commonly used for recording the energy flowing in an electrical circuit for a certain period of time is the watt-hour meter, since it records the product of the watts and the time. The "recording wattmeter" in the true sense of the word is the instrument which is ordinarily known as the graphic, or "curve-drawing wattmeter," which records the watts for any given instant without taking into consideration the time element.

Relation of the Meter to the Central Station.

The relation of the meter and the meter system to the distributing station is a factor of great importance, the gravity of which, as a rule, is not fully realized; especially is this true with the small and the medium-sized lighting and power companies. The revenue of the distributing company depends on the meter in more ways than are at first apparent,and the continued accuracy of its meters is a matter materially affecting its financial success. Inaccurate meters are eventually detrimental to the interests of the company selling current, regardless of whether the meter runs fast or slow. A fast meter furnishes the consumer a very just cause for complaint, and when detected usually reacts strongly against the company in producing mistrust of its methods and a general feeling among its customers that they are paying for something that they never receive. Such a feeling is to be avoided by every possible means, as it causes endless complaints and in many cases the loss of customers with the resulting loss in revenue.

Slow meters, of course, act directly on the company's revenue, failing to record the power which is actually being delivered. This is often a very serious source of loss, especially where meters are operating at light load for a considerable portion of the time, as is almost always the case under commercial conditions. It is this inaccuracy in meters at light loads that constitutes, in the majority of cases, the chief source of loss to the distributing company, and especially is this true where there is no attempt made to periodically test the meters and make any minor adjustments that may be necessary. Meters are often installed under conditions that are by no means the most favorable for a delicate piece of apparatus; this however, is frequently unavoidable, as the meter must be installed wherever power is sold. It is often installed in places which are inaccessable, allowed to become covered with dust and dirt, and in some cases it is placed where it is subjected to severe and continual vibrations; it is usually then left to take care of itself, receiving no further attention than to be read once a month. Under such conditions it is almost inevitable that the meter will eventually run slow, especially on light loads.

In carefully managed and well designed direct current systems, the energy lost in line drop and otherwise unaccounted for between the station bus-bars and the consumer's meters may be as low as 15 per cent, but on alternating current systems, having many small transformers connected to the lines which are continually consuming power in the form of core loss, and with meters which are poorly maintained or entirely neglected, the loss shown by the comparison of the reading of the station meters and the consumer's meters may be as high as 70%. From 15% to 20% represents very good practice on direct current systems, and from 20% to %30 on alternating current systems.

The Selection of Meters.

The selection of meters is a question which should be thoroughly investigated. While there are several excellent makes of watt-hour meters on the American market, there are still others which may be disastrous to the revenue of the distributing company. It is not always the meter which when new shows itself capable of finer adjustments and consequent high initial accuracy that will prove the most satisfactory or the most accurate after a period of service under average commercial conditions. Of course initial accuracy is an important factor, but it should not be sought at the expense of continued accuracy. The meter should be of as substantial and rugged construction as is consistent with efficient design. Such a meter will prove to be more satisfactory and will show less error after a period of service than will a meter of more delicate construction, although when new it can be adjusted to a finer degree. This question of continued accuracy is of paramount importance and should always be borne in mind while selecting the instrument upon which the revenue of the company is to depend.

Factors Affecting a Meter's Accuracy.

The factors affecting the accuracy of a watt-hour meter are various, but the two principle ones are friction and the weakening of the permanent magnets. If these two factors could be eliminated, a meter once accurately adjusted would remain so indefinitely. Unfortunately, however, these two factors do play a very serious part in the performance of the meter, the most serious being friction. If the friction component was a constant quantity it could be compensated for by the light load adjustment device and thus permanently eliminated as regards the meter's accuracy. It has been found though that friction is an extremely variable quantity and in the case of any motor-meter it may vary by quite a large amount, even under very favorable conditions. For this reason a high value of the torque, or turning effort is very desirable, since with a high torque the percentage of this torque required to overcome any increase in friction is relatively small, and the percentage increase of effective torque due to any decrease in friction is also correspondingly small. Thus it will be seen that a meter having a high torque will not suffer in accuracy nearly so much for the same amount of change in friction as will a meter of low torque. There is, however, a value for the torque, which if exceeded, will result in poor economy, because by increasing the losses a higher value of torque can be produced. It can therefore be readily seen that the design of a meter should be such that this ratio of torque to watts loss will be at the most economical point.

Since friction is the most serious factor affecting the accuracy of a watt-hour meter, it is essential that every care and precaution be taken both in the design and the manufacture to insure low initial friction, and to insure as far as possible against changes in friction after the meter has been in service for some length of time. Friction will develop in the lower jewel bearing, in the upper bearing and in the recording mechanism.

The Jewel Bearing.

In order to obtain low friction in the jewel bearing the revolving element should be light in weight; only the highest grade of jewels should be used, and they should be carefully selected and ground. The pivots, or the bearing points, should be of the finest grain of glass-hardened steel. It is usual practice of manufacturers to mount the jewel on a spring support, thus taking up any sudden vibrations and thereby preventing excessive pressure between the jewel and the bearing point, therefore prolonging the life of each. Although the actual weight supported by the lower bearing is small, the pressure between the jewel and the pivot in a meter is great, since the actual contact area is exceedingly small, being as it is, almost a "point" contact, so that the pressure per square inch of contact reaches an extremely high value. It is for this reason that jewels of the best quality and "glass-hardened" steel pivots are necessary in the construction of the lower bearing, as any other material would quickly break down and develop excessive friction. The otherwise objectionable "point" contact between the jewel and the pivot is necessary in order that low initial friction may be secured.

Recording Mechanism.

When properly and carefully made, the recording mechanism is not subject to the variations in friction which occur in the bearing, and it can therefore be much more completely compensated for by means of the light load adjustment device of the meter. Only machine cut gears should be used in the construction of the recording mechanism, and during the course of manufacture every precaution should be taken to see that the gears and their bearings are in perfect condition and free from all burrs; even the slightest burr or imperfection in the individual gears will prove to be a source of friction variation, and as some of the gears move very slowly and as friction variation would only appear when the imperfect portion was in mesh, the only feasible way of detecting and preventing this source of future error in the meter is by rigid factory inspection of all parts which enter into the construction of the recording mechanism.

Weakening of the Permanent Magnets.

The next important factor affecting the continued accuracy of the watthour meter, and one of a very serious nature, is the weakening of the permanent magnets, often called the "retarding magnets." The only insurance which the purchaser has against a poor grade of permanent magnet is the ability and the experience of the manufacturer. It sometimes happens that meters, especially for switchboard service, are installed where they are subjected to the influence of powerful "stray fields" which may be set up, due to the proximity of wires or bus-bars carrying heavy currents. To nullify the effects of such stray fields on the retarding magnets, some manufacturers arrange the magnets astatically, that is, they are placed so that any stray field which will tend to weaken one magnet will correspondingly strengthen another, and vice versa.

Creeping.

Under the same category as fast meters comes the "creeping" of meters. It is sometimes found that meters will run slowly, or "creep" when there is no current flowing in the series fields, the potential circuit alone, being energized. This is due to the light load adjustment exerting more than enough torque to overcome the friction, and may be due to one or more causes. The light load adjustment may be so set that it just compensates for the initial friction and the meter then installed where it is subject to continual vibration, under which condition, the "friction torque" is reduced and the meter will creep. Again, the meter may be on a circuit where the voltage is above normal, which will tend to produce creeping. As a general rule, meters are so adjusted at the factory as to allow for a range of several per cent in voltage without causing creeping; such practice is to be recommended, as the slight benefit to be derived from having the friction completely compensated for is more than counterbalanced by the trouble due to creeping when such fine adjustments are made.

Overmetering.

Another frequent and easily avoidable source of loss to the distributing company is "over-metering." It often happens that in the case of public buildings, theaters and other places where there is a large "connected" load, and where for a greater part of the time only a small part of this connected load is actually taking current, that one large meter of sufficient capacity to take care of the entire installation is employed. When this is done the large meter will operate the majority of the time on light load, and for a considerable portion of the time it may be operating on very light loads, and since no commercial meter can be relied upon to continuously record such light loads with the same accuracy as at or near full load, there will result a considerable loss from the practice of "overmetering." It is often much better to install a smaller meter to take care of such loads, even at the risk of an occasional burn-out. Practically all standard meters will carry a considerable overload for short periods, and will carry as much or more than 25% overload continuously when located in cool, dry places. It is not recommended that meters be worked at overloads continuously, but in many instances it will be economy to have them work at overloads during the period of maximum demand. By exercising a little judgment a meter can be so selected that it will never be excessively overloaded, but which will be small enough to give a fair degree of accuracy during the light load period.

Where the ratio of the connected load to the average actual load is large, it is better to subdivide the circuits and install two or more meters than to attempt to handle the entire load on one meter. In this way it can be so arranged that while there is no danger of a meter being severely overloaded, it will still be small enough to accurately record the power during the light load period.

General Construction.

The different types of meters will be dealt with separately hereafter, therefore we will take up at this point the various parts which are common to all types.

Frames and Covers: The supporting frames to which the mechanism is secured should be rigidly constructed from a mechanical standpoint, and the material used should be non-magnetic. The covers should be of sufficient rigidity to protect the meter from ordinary mechanical injury, and should also be light; the composition known as "white metal" is a good material, being used either in its natural finish or with a coating of dull black japan. In some cases glass is used for the covers so that all working parts of the meter may be superficially inspected without removing the cover. For switchboard meters, glass is a satisfactory material for the covers, but for ordinary house type meters the metal covers are to be recommended; glass covers, exposing all parts of the interior to view, may tend to invite tampering by unauthorized persons. The internal frame which actually supports the bearings and other parts of the meter proper

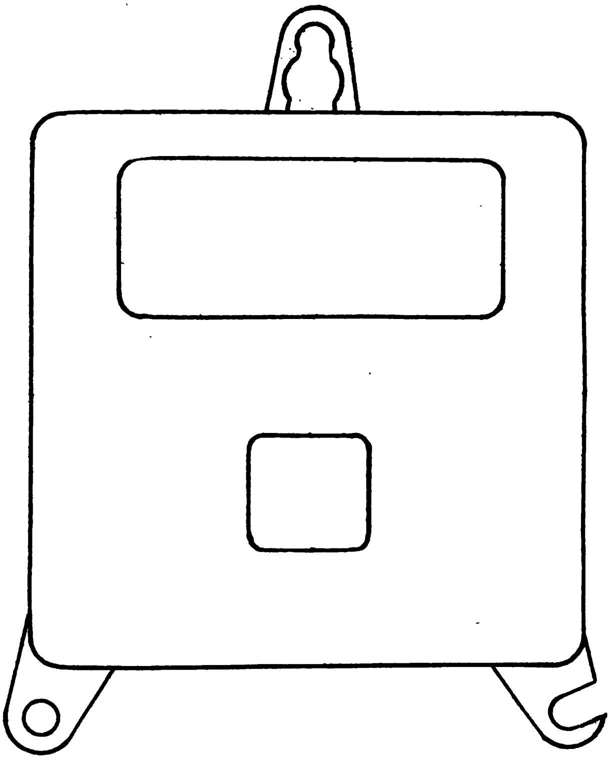


Fig. 1. Supporting Lugs of Base Frame.

should also be made of non-magnetic material. In the ordinary type of "commutating" meter the construction of the internal frame is such that when used on alternating currents it is often the case that heavy eddy currents may be induced in the frame by the rapid reversals of the "projected" field. Such eddy currents cause undue heating, and to obviate this some manufacturers split the frame and insert a piece of fibre or other insulating material.

The base frame is usually furnished with three supporting lugs as shown in Fig. 1, the top lug being key-holed and the lower right hand one slotted, thus allowing the meter to be rapidly hung in place. It can then be properly levelled and set and the supporting screws driven home.

The removable covers are usually held in position by two or more studs which are fastened to the base frame and which project up through the covers; wing-nuts having holes through their bodies, through which seal wires may be passed, are used on the studs to securely hold the covers in place. The groove in the base frame into which the covers fit, should be provided with felt gaskets to exclude dust, moisture and insects from the interior of the meter. The holes for the entrance and exit of service wires should also be provided with a dust proof feature, and the dial window should be set in putty or other suitable material.

The Top Bearing: The top bearing of a meter is necessarily simple, as it does not have to support any weight, but simply acts as a guide bearing, and may be the same as or similar to either of the two types shown in Fig. 2.

The Shaft: The shaft should be made as light as is consistent with good design, and is usually made of steel approximately 1/8-in. in diameter, some manufacturers using a solid shaft, and others a tubular form. At the top of the shaft is mounted the "worm" gear which transmits the motion of the shaft to the recording mechanism. There are two general methods of constructing the worm; one consists of cutting it directly into the steel shaft, the other method being to mount a worm of composition material in the end of the shaft. This latter method possesses the advantage of allowing the use of a non-rusting material. On the lower extremity of the shaft is mounted the removable pivot.

Discs: Until several years ago, the meter discs were made almost exclusively of copper on account of its high conductivity, but aluminum has practically superseded copper for this purpose, due to its lighter weight. An aluminum disc having the same conductivity as a copper disc will weigh only about 48% as much as the copper. Therefore the aluminum, though of greater thickness, is much more desirable. The question is often asked: "Why are most meter discs roughened or covered with little holes which resemble prick-punch marks?" This has nothing whatever to do with the electrical characteristics of the meter, as is sometimes supposed, but simply results from a factory method of producing a plane surface. The disc is placed on a heavy metal block, and a weight having a roughened surface is allowed to fall upon the disc, thus producing the peculiar marking. It has been found that this process eliminates any trouble which may be due to the warping of the disc.

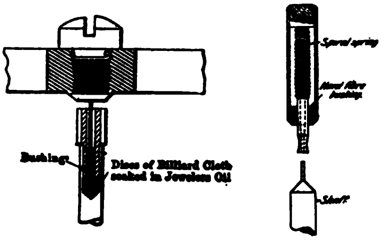


Fig. 2. Types of Top Bearing.

The Lower Bearing: There are at the present time two general types of lower bearings in use; the pivot and jewel type as shown in Fig. 3, and the ball and jewel type as shown in Fig. 4. The ball bearing is relatively a new departure, but in reality it is essentially a "pivot" bearing also, and as far as the comparative friction is concerned, they are, it is safe to say, about equal. So long as the ball remains perfectly smooth and free from rust it serves its purpose admirably.

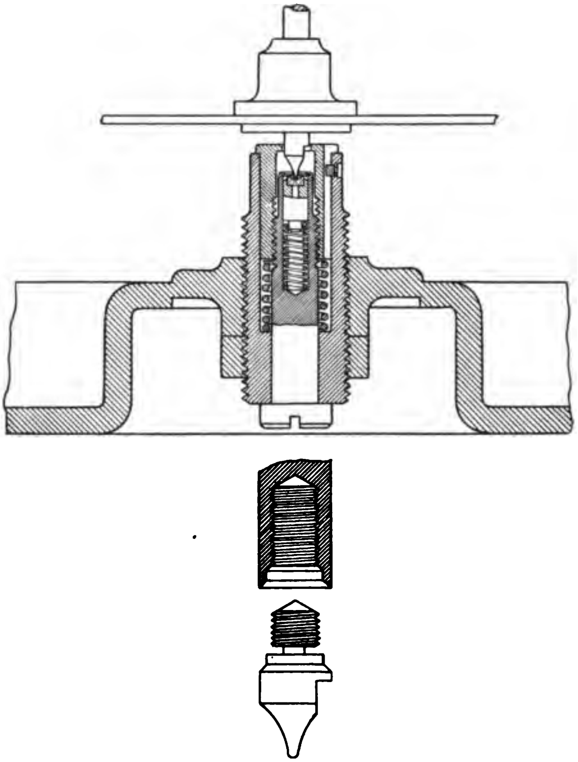


Fig. 3. Pivot and Jewel Type of Lower Bearing.

Jewels: It has been found that there are but two kinds of jewels which are satisfactory for use in the lower bearings of meters, they being the diamond and the selected eastern sapphire. In self-contained meters, up to and including 50 k. w. capacity, the sapphire is generally used to the best advantage; above this value, it is advisable to use the diamond, because of its unequalled hardness. Where great accuracy is desired in the case of switchboard meters in central stations, it is often desirable to use diamond jewels in meters of as small a capacity as 5 amperes. In all cases, the jewel should be carefully selected, ground and polished, and should be free from all flaws. It has been noted that under normal conditions, the average sapphire jewel will stand as much or more than 600,000 revolutions of the shaft, and in some

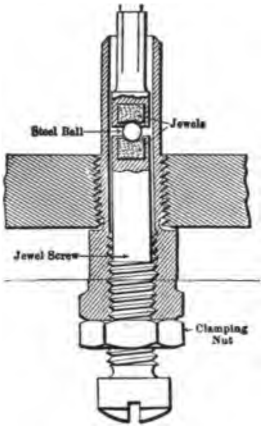


Fig. 4. Ball and Jewel Type of Lower Bearing.

cases the diamond jewel has lasted for as many as 35,000,000 revolutions of the shaft. These values, however, are extremely variable and depend to a great extent upon the conditions and care under which the meter operates.

The Retarding Magnets: It is of the utmost importance that the strength of the retarding magnets be as permanent as is possible to make them, since their retarding or "dragging" effect is proportional to the square of their magnetic strength. Therefore a slight change in the strength will have an appreciable effect upon the speed of the disc. Much depends upon the physical properties of the steel from which the magnets are manufactured, and the most rigid inspection, by both chemical and physical analyses should be made of each lot of steel before it is treated for use as meter magnets. The manufacturer, after he has given the steel a special process of treatment, hardens, forms and magnetizes the product. The completed magnet is then subjected to hammer blows to detect any mechanical imperfections, and if it should fail to "ring true" is rejected. It then undergoes an artificial aging process; accurate measurements of magnetic strength being made at frequent intervals. It is then laid away for several months after which the strength is again measured and if this latter measurement differs in the least from its strength when first laid away it is discarded.

A very successful process of magnetizing meter magnets consists in slipping the completed form over a copper bar, through which a heavy current of electricity (many thousands of amperes) is passed momentarily. In this way a great number of forms can be magnetized at the same time, and a uniform strength produced. Great care is taken in the manuture of the permanent magnets, and as a rule the results are very satisfactory.

The Recording Mechanism: As previously pointed out, the recording mechanism should be manufactured with the greatest care, and rigid factory inspection is practically the only safeguard against imperfections. Meters are often placed in such positions that the meter reader will encounter reflected light, and for this reason it will generally be found that a dial of unglazed material will be less difficult to read under all conditions. The recording mechanism should be so constructed and provided with such dowel pins that it can be removed from the meter at any time and then replaced in the exact position from which it was originally taken without disturbing in the least the mesh of the worm with the first gear.

From the foregoing description of the general construction, a very good idea can be gathered as to the mechanical requirements of a good meter; a study of the subsequent chapters treat of the electrical characteristics.

There are still to be found throughout the country a number of the very old type "low efficiency" meters, and a great many of the ampere-hour type; it is the recommendation of the authors to replace such old metors with some make of good modern watthour meter, as in the majority of cases the increased revenue to be derived will pay many times for the interest on the cost of the exchange.

CHAPTER II.

THE MEASUREMENT OF POWER.

The power in a direct current circuit is equal to the product of the electro motiveforce and the current; in other words, if I represents the current in amperes, and E, the e.m.f. in volts, then the

$$\text{Watts, } W = EI\text{, or the kilowatts} = \frac{EI}{1000}$$

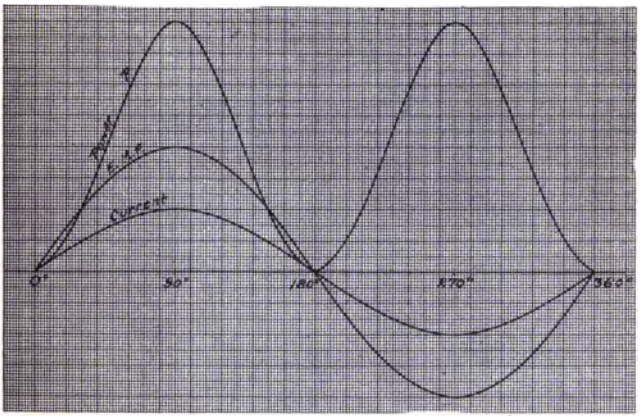


Fig. 5.

The power flowing in a direct current circuit can therefore be determined by the use of a voltmeter and an ammeter, or by one instrument, an indicating wattmeter, which will indicate the product of the volts and amperes.

The power flowing in an alternating current circuit is dependent not only upon the e.m.f. and the current, but also upon the power factor of the circuit. This is evident as is illustrated by Fig. 5, which shows a sine wave of e.m.f and current at unity power factor. In Fig. 6 is shown the same current and e.m.f. but with a power factor of 50 per cent instead of unity. The instantaneous value of the power flowing in any circuit is equal to the product of the instantaneous value of the e.m.f., and the instantaneous value of the current.

The curve P represents these instantaneous values of the power. It will be noted that in the case of unity power factor (Fig. 5), the curve P is entirely above the axis, that is the line of zero value; this indicates that the power is all flowing in one direction. It will also be noted that the maximum value of the e. m. f. occurs at the same instant as the maximum current, which condition gives the maximum value of the power for these values of the current and the e.m.f., as can be seen from the figure.

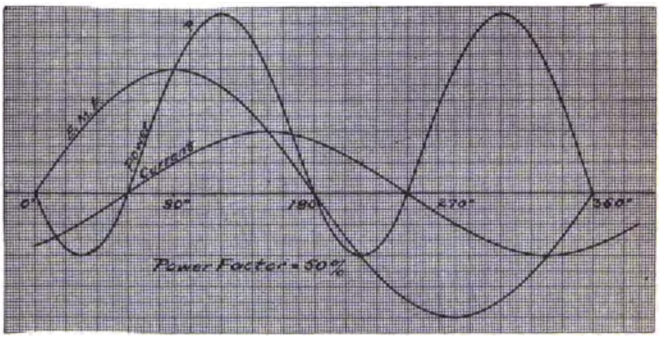


Fig. 6.

Referring to Fig. 6, it will be noted that for a power factor of 50 per cent, part of the curve, P, is below the axis, which indicates that the power is not all flowing in the same direction, but that during a part of the cycle a portion of the power is actually being "pumped back" into the circuit. The net value of the power supplied is equal to the difference between that represented by the area enclosed by the curve, P, which is above the axis and the area enclosed by that part of the curve which is below the axis.

Assuming a sine wave of e. m. f., and of current (modern commercial alternating current generators give waves closely approximating a sine wave), and denoting the maximum value of the e.m.f. by $\mathbf{E}$, the maximum value of the current by $\mathbf{I}$, and the instantaneous value of the e.m.f. by e, we have

$$e = \mathbf{E} \sin \phi,$$

where $\phi = \omega\ t$, in which $\omega = 2\pi f$ (f being the frequency of the circuit in cycles per second) and t = the time in seconds measured from the instant when the e.m.f. crosses the axis in a positive or rising direction.

The instantaneous value of the current, $i = \mathbf{I} \sin (\phi - \theta)$, where $\theta =$ the angle of phase displacement between the current and the e. m. f. The instantaneous power, p, is equal to the product of the instantaneous e. m. f. and the instantaneous current, or

$$p = e\ i, = \mathbf{E} \sin \phi\ \mathbf{I} \sin (\phi - \theta)$$

$$\text{or } p = \mathbf{EI} \cos \theta \sin^2 \phi - \mathbf{EI} \sin \theta \sin \phi \cos \phi.$$

Let P = the average value of p,

$$\text{then } P = \text{av'g } (\mathbf{EI} \cos \theta \sin^2 \phi - \mathbf{EI} \sin \theta \sin \phi \cos \phi)$$

$$= \mathbf{EI} \cos \theta\ (\text{av'g } \sin^2 \phi)\ \text{EI} \sin \theta\ \text{av'g } (\sin \phi \cos \phi).$$

The average value of $\sin \phi = \frac{1}{2}$, and the average value of $\sin \phi \cos \phi = 0$, substituting these average values in the above equation, we have

$$P = \frac{\mathbf{EI} \cos \theta}{2}$$

But $\mathbf{E}$, the maximum value of the e.m.f. wave$= \sqrt{2}\, E$, where E is the effective value of the e.m.f. Also, if I denotes the effective current, the maximum current, $\mathbf{I} = \sqrt{2}\, I$. Therefore, we have the fundamental formula:

$P = EI \cos \theta$; the $\cos \theta$ being the power factor of the circuit.

If the power factor is unity, then $\cos \theta = 1$, and hence the above equation becomes $P = EI$, which, as will be noted, is the same as for direct current. The power factor is very seldom as high as unity, and it is therefore almost always necessary to use a wattmeter rather than a voltmeter and ammeter; a properly constructed and accurately calibrated wattmeter

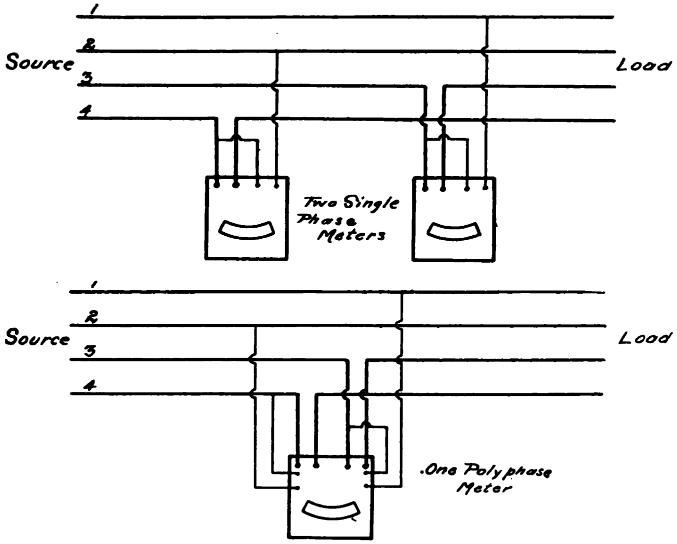


Fig. 7.

will measure power correctly regardless of the value of the power factor. The power factor of a single phase alternating current can be easily obtained by taking the product of the volts and the amperes as indicated by a voltmeter and ammeter and dividing this result into the actual power reading as indicated by a wattmeter.

The actuating force in an indicating wattmeter is derived from two sets of coils, one being connected in multiple, and the other in series (as in the case of the watthour meter) with the load to be measured. The reaction between these two coils is at each instant proportional to the instantaneous values of the current and the e. m. f., so that the total deflecting force acting on the pointer of the instrument is at all times proportional to the true power.

A two-phase system (often called "quarter phase"), can be considered as two single phase systems, and the power being supplied by such a system is simply the sum of the power flowing in the two equivalent single-phase systems, and can be measured by a single-phase wattmeter in each system, or by one polyphase wattmeter as shown in Fig. 7, in which lines 1 and 3 constitute one-phase and 2 and 4 the other phase.

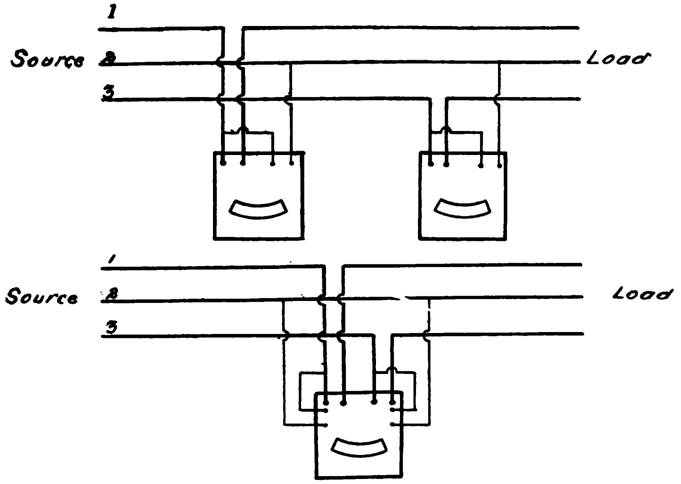


Fig. 8.

The power in a two-phase three-wire system can also be measured by two single-phase wattmeters or by one polyphase wattmeter, the connections being made as shown in Fig. 8, in which line number 2 carries the resultant current. Fig. 9 shows the connections used when measuring power in a **balanced** two-phase three-wire system with one single-phase meter. In this case the voltage impressed on the meter will be $\sqrt{2}$ or 1.41 times the voltage of either phase, and when the system is balanced the current flowing in the line, 2, will also be $\sqrt{2}$, or 1.41 times the current in either phase. The one wattmeter method will measure the true power only when the phases are perfectly balanced, and is therefore very seldom used.

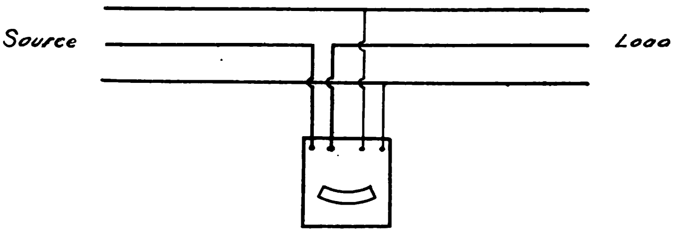


Fig. 9.

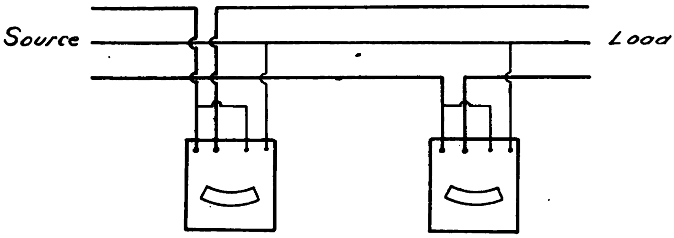


Fig. 10.

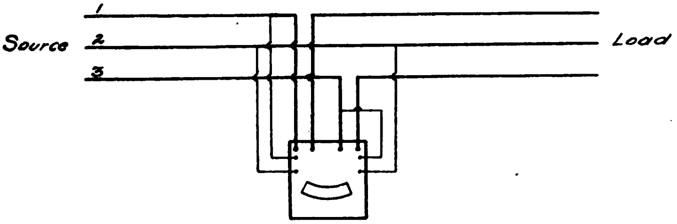


Fig. 11.

The power flowing in a three-phase system can be measured by two single-phase meters connected as shown in Fig. 10, or by one polyphase meter connected as shown in Fig. 11.

The power in a three-phase four-wire system can be measured by three single-phase wattmeters connected as shown in Fig. 12; the three-phase four-wire system being virtually three single-phase systems. The total power will be the sum of the indications of the three meters. The power in a three-phase four-wire system can also be measured by two single-phase meters connected as shown at (a) in Fig. 13, or with one polyphase meter in conjunction with current (or series) transformers connected as shown at (b) in Fig. 13.

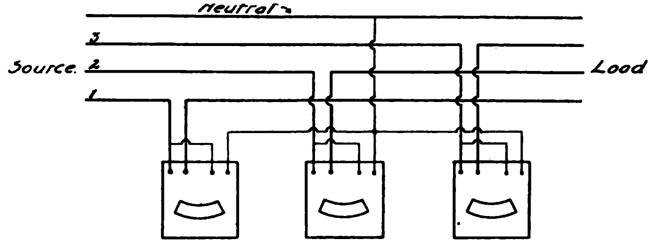


Fig. 12.

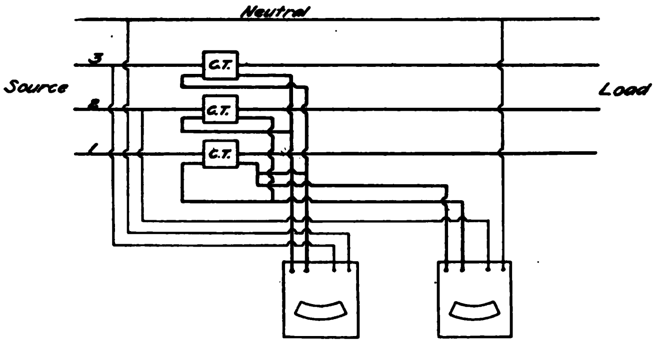


Fig. 13a.

The power flowing in a three-phase system is expressed by the equation, $P = \sqrt{3}\ EI, \cos \theta$, where E is the voltage between the phases, I the current per leg and cos θ, the power factor of the circuit, When the system is not balanced the average values of the current, the voltage and the power factor should be used in the above equation, remembering that θ is the angular displacement between the line current and the voltage between line and neutral.

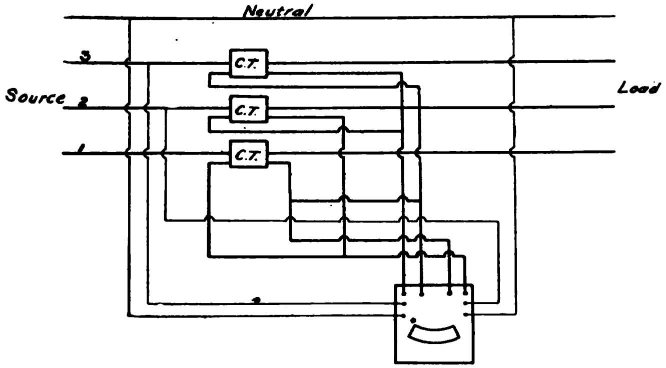


Fig. 13b.

Fig. 14 shows the method of connecting one single-phase wattmeter for measuring the power in a balanced three-phase three-wire system.

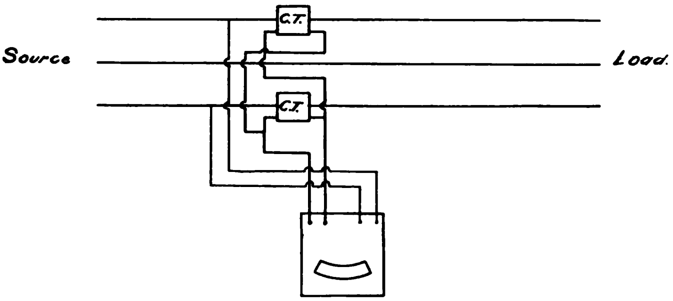


Fig. 14.

Power is the rate at which energy is supplied. Electrical power is measured in watts and kilowatts, and electrical energy is measured in watt-hours and kilowatt-hours. "Purchasers of power" are in reality purchasers of energy, and in order to determine the energy flowing in a circuit it is necessary that the power be multiplied by the time. If w = the power in kilowatts, and t = the time in hours during which the power is flowing, then the energy = w t = kilowatt-hours. Since it is energy and not power which is bought, it is necessary to have an instrument which will take into consideration the time element; such an instrument is the watthour meter.

CHAPTER III.

THE INDUCTION METER.

At the present time the induction type of watthour meter is used almost exclusively where alternating currents are concerned, and as alternating current is much more extensively used for general lighting and power distribution than is direct current, there are considerably more induction meters being manufactured than there are of any other type.

Reasons for Its Extensive Use.

Some of the principle reasons for this almost exclusive use of the induction meter on alternating current circuits are as follows: The induction meter is more rugged in design, having no brushes, no commutator, or other moving contacts. The revolving element consists simply of the shaft and revolving disc, all windings being on the stationary element.

The weight of the moving element being less than that of the commutating type of meter, and the fact that it has no commutator with its resulting friction, necessarily eliminates an appreciable amount of friction and also results in less jewel wear.

For the above reasons, the induction meter will maintain its accuracy better with the same amount of attention than will other types of "motor" meters.

The induction meter is entirely free from commutator and brush troubles, having neither brushes nor commutator. It is cheaper in first cost than any other type of meter, suitable for use on alternating currents, which can compare with it in continued accuracy.

Principle of Operation.

The induction meter consists essentially of the stationary element, the rotating element (consisting merely of the shaft and disc), the recording mechanism, the jewel bearing and the retarding magnets.

The stationary element consists of the magnetic circuit, A, Fig. 15, which is built up of laminated steel punchings; the current coils, B; the potential coil, C; the light load adjustment, D; and the lagging coil, E. The current and potential coils are mounted as shown in the figure, in such a way that the magnetic flux set

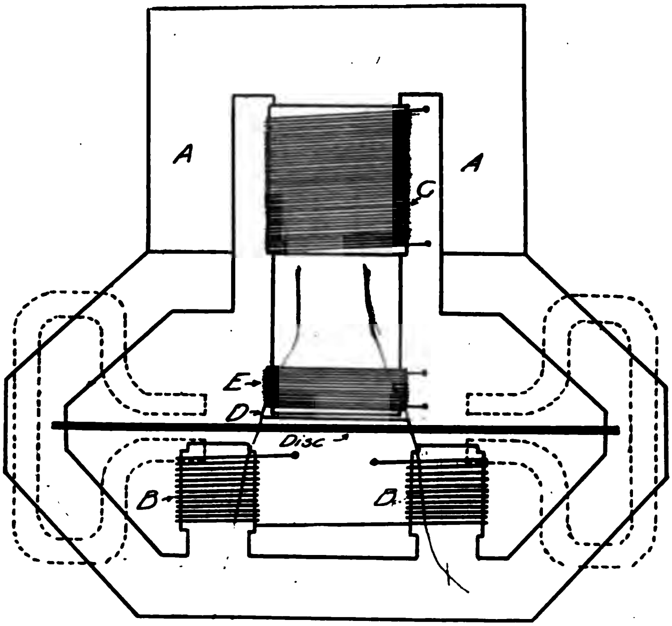
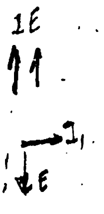


Fig. 15.

up by each of these coils will pass through the meter disc, and this alternating flux passing through the metallic disc will set up currents therein which will flow as indicated in Fig. 16, the disc acting virtually as the short-circuited secondary of a transformer. It will be seen from Fig. 16 that the currents set up in the disc by the potential coil P flow past the poles of the current coils, P^1, and that the currents set up by the current coils flow past the pole of the potential coil. These currents set up in the disc are in phase with the voltages producing them, since the circuit offered by the disc itself is non-inductive. The voltages in the disc which produce these currents, however, lag 90 degrees behind the **fluxes** set up by the coils on the stationary element, as an induced voltage is always 90 degrees behind the inducing flux. The flux is in phase with the current which produces it, the angle of hysteretic lag being negligible, so that we have currents flowing in the disc lagging 90 degrees behind the currents flowing in the meter windings.



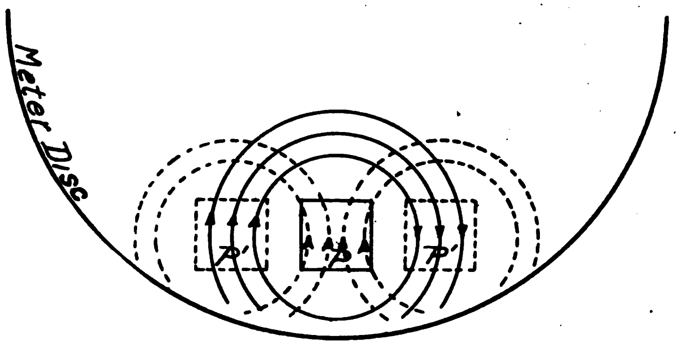


Fig. 16.

The potential coil is wound with many turns of fine wire, and is therefore highly inductive, so that the current flowing in this coil is practically 90 degrees behind the impressed e.m.f, and the flux from the pole of the potential coil is brought to exactly 90 degrees behind the impressed e.m.f. by use of the lagging coil, as will be explained later. The flux from the poles of the current coils will be in phase with the current, and therefore in the case of a load of unity power factor will be in phase with the impressed e.m.f. It can be readily seen from this that in the case of unity power factor the current set up in the disc by the potential coil (which lags 90 degrees behind the flux from the potential coil), will be in phase with the **flux** from the current coils, and also that the current set up in the disc by the current coils will be in phase with the flux from the potential coil. It will further be seen by referring to Fig. 16 that the disc currents set up by the potential coil will flow past the center of the current coil poles, and that the disc current set up by the current coils will flow past the center of the potential coil pole. This will give rise to a mechanical force tending to cause the disc to revolve, since any conductor carrying current at right angles to a magnetic field is subjected to a force which tends to move the conductor out of such field. Furthermore, this force is proportional to both the current flowing in the disc and to the field strength or to the product of these two factors. In the case of the meter the current flowing under the pole of the potential coil is proportional to the line current, and the flux is proportional to the impressed e.m.f. Similarly, the current flowing under the poles of the current coils is proportional to the impressed e.m.f. and the flux from the current coil poles is proportional to the line current. The force tending to revolve the disc is therefore proportional to twice the product of the current and the voltage, or what is the same thing, it is proportional to the product of the current and voltage, or to the watts.

The principle of the induction meter's operation may be explained in a somewhat different way, which is perhaps more clearly understood; that is, the electrical element may be considered as the stator of an induction motor and the disc as the rotor. The "shifting" magnetic field in the case of a meter (which corresponds to the "revolving" magnetic field of the motor), is supplied by the current coil and the potential coil poles, the flux from the potential coil pole being 90 degrees out of phase with the flux from the current coil poles, as previously explained. This "shifting" magnetic field sets up currents in the meter disc, which reacting with the magnetic field produces a force tending to rotate the disc, exactly as the "revolving" field of an induction motor sets up currents in the rotor, which reacting with the "revolving" magnetic field produces a torque which causes the motor to run.

In the case of power factors which are other than unity, the flux produced by the current coils (which flux is in phase with the current), will no longer be 90 degrees out of phase with the flux from the potential coil, but will be 90 degrees plus or minus the angle of current displacement or the angle by which the current is out of phase. This being the case, the disc currents set up by these coils will no longer be in phase with the flux from the poles under which they flow, but will be out of phase by the angle of current displacement. The force tending to turn the disc will therefore no longer be directly proportional to the product of the current and the flux, but it will now be proportional to the product of the current, the flux and the cosine of the angle of current displacement, which is the power factor. Therefore the meter will still register the true watt-hours.

Another way of expressing this is to consider that the force acting on the disc will be proportional to the product of the flux and the **component** of the disc current which is in phase with the flux. Since the disc current is out of phase with the flux by the angle of current displacement, the component of the disc current in phase with the flux is equal to the total disc current multiplied by the cosine of the angle of displacement, or the power factor.

Lagging for Low Power Factor.

In order for the meter to register correctly on low power factors it is necessary for the flux from the pole of the potential coil to be **exactly** 90 degrees behind the impressed e.m.f. If the flux from the potential pole is less than 90 degrees behind the impressed e.m.f. the meter will run slow on lagging and fast on leading currents, while if the flux lags more than 90 degrees it will run fast on lagging and slow on leading currents. This condition is obtained by a method known as lagging, and is accomplished as follows: In figure 15

C is the potential coil, and E is the lagging coil which is mounted over the pole tip of the potential coil. The current in the potential coil will be not quite 90 degrees behind the impressed e.m.f., due to the RI^2 losses in the winding and the losses in the iron which give rise to an energy component of the current. The flux will be in phase with the current, and will therefore be not quite 90 degrees behind the impressed e.m.f. A part of this flux will pass through the lagging coil and on through the meter disc. This flux induces an e.m.f. in the lagging coil which is 90 degrees behind it in phase. This is shown by the vector diagram, Fig. 17. In this diagram OE represents the impressed e.m.f. and OI the current in the potential coil which lags not quite 90 degrees behind this e.m.f. $O\phi$ represents the flux set up by the current, which passes through the lagging

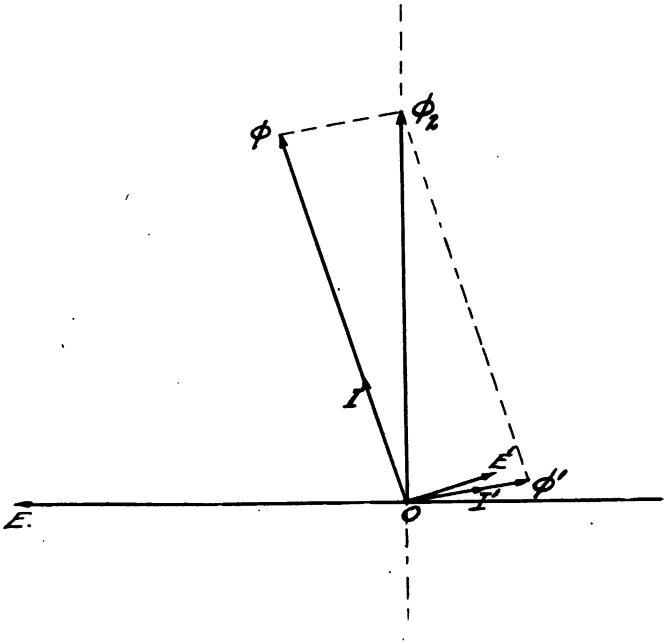


Fig. 17.

coil and meter disc. This flux induces the e.m.f., OE', in the lagging coil, which is 90 degrees behind it in phase. The circuit of the lagging coil is closed through a resistance, the amount of which can be varied and therefore the amount of current flowing in this circuit can be varied. This current is represented in the diagram by OI'. The current OI' will set up a flux $O\phi'$ in phase with itself, and this will combine with the flux $O\phi$, producing the resultant flux, $O\phi_2$, which will pass through the meter disc. It can be readily seen by reference to the figure that if the current, OI' is of the proper value, that this resultant flux $O\phi_2$ will be exactly 90 degrees behind the impressed e.m.f., OE. By adjusting the amount of non-inductive resistance in the circuit of the lagging coil, this condition can be very easily produced, which process is known as "lagging." A properly lagged meter will register with accuracy on low power factor. The method of lagging above described is used in meters manufactured by the General Electric Company.

The method of lagging which is employed in meters manufactured by the Westinghouse Electric and Manufacturing Company is somewhat different from that which has just been explained, though the principle is essentially the same. In the Westinghouse meter the lagging coil consists of an adjustable short-circuited turn, placed on the pole tip of the potential coil. The position of this turn can be adjusted so as to obtain the required flux component to bring the resultant flux 90 degrees behind the impressed e.m.f. By referring to Fig. 18 it will be seen how this is accomplished. OE represents the impressed e.m.f., OI, the current in the potential coil, OE', the voltage induced in the short-circuited lagging turn, OI', the corresponding current, and $O\phi'$ the flux set up by this current. $O\phi_2$ represents the resultant flux which lags 90 degrees behind the line e.m.f. The proper value of the flux, $O\phi'$ can be obtained by varying the position of the short-circuited turn.

In the induction meter manufactured by the Fort

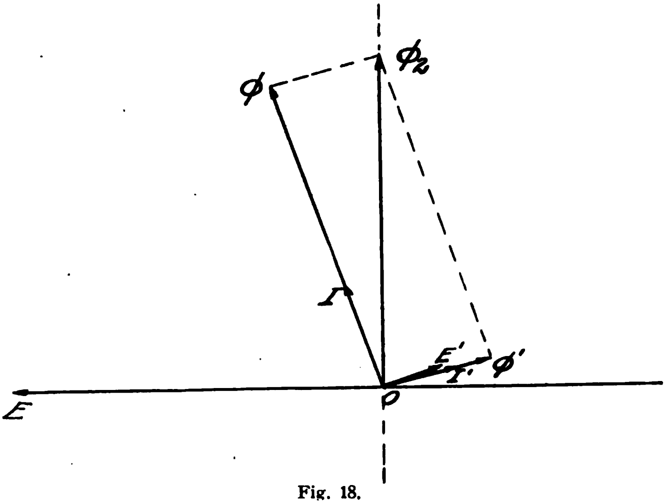


Fig. 18.

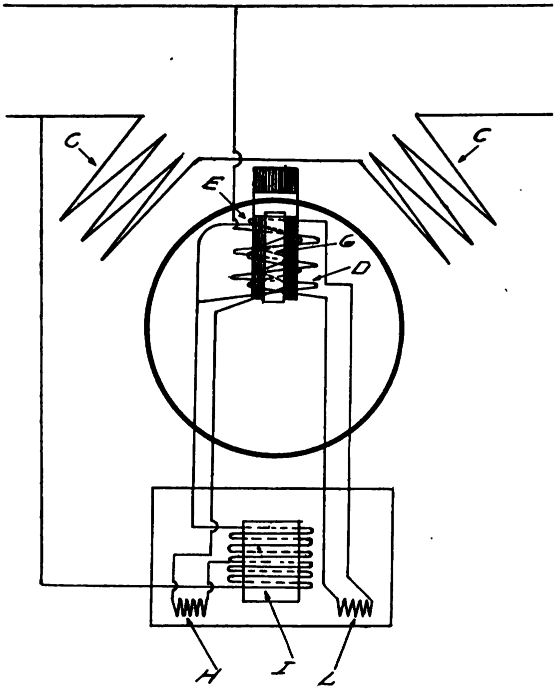


Fig. 19.

Wayne Electric Works, the lagging device consists of two elements, one being wound on the light load adjusting arm (shown at G, Fig. 19), and is connected in series with the lagging resistance, H. This coil and resistance is shunted across a portion of the potential winding as shown. The other coil, E, is wound on the potential pole tip and is short-circuited through a resistance, L. In the vector diagram, Fig. 20, OE is the impressed e.m.f., OI, the current flowing in the potential circuit, which lags not quite 90 degrees behind the voltage, and Oϕ is the flux produced by this current.

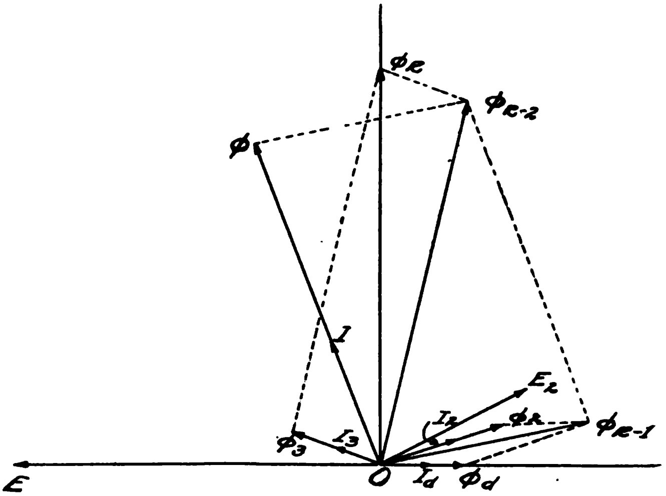


Fig. 20.

This flux produces the voltage OE$_2$ in the lagging coil, E, which in turn sets up the current OI$_2$, and the flux, Oϕ_2. The current induced in the meter disc by the potential coil also sets up a flux, Oϕ^d, in phase with itself. The resultant of Oϕ_2 and Oϕ^d, which is represented by OϕR$_{-1}$, combines with Oϕ giving the resultant flux OϕR$_{-2}$, which lags more than the required 90 degrees, and this is brought to exactly 90 degrees by the flux Oϕ_3 set up by the coil, G. The flux Oϕ_3, being almost in phase with OE, the voltage impressed on the coil being in phase with OE, and the circuit being closed through a non-inductive resistance. The proper amount of lagging is accomplished by adjusting the resistances H and L, which changes the values of the currents OI_2 and OI_3, and therefore the fluxes produced by them. Coil L is left open-circuited when used on 133 cycles, the flux from the meter disc producing the necessary lagging effect in conjunction with the coil, H. Such a meter as just described is "double lagged," since the 60 cycle meter can be used on 133 cycles by simply open-circuiting coil L.

Light Load Adjustment.

The light load adjustments of the various makes of induction meters on the American market are very similar in principle of operation, as is also the case with the power factor adjustments. The different manufacturers, however, use somewhat different methods of applying the fundamental principle as will be seen in the following descriptions:

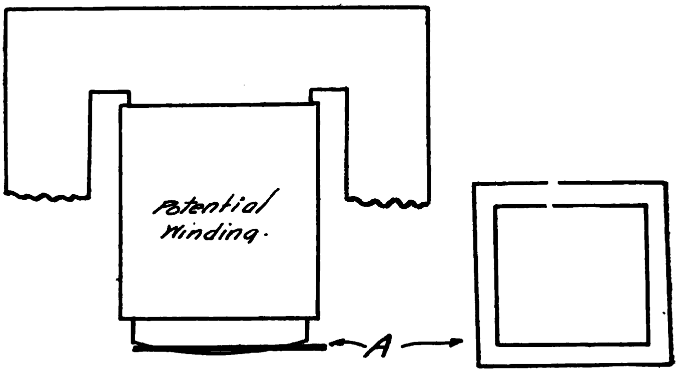
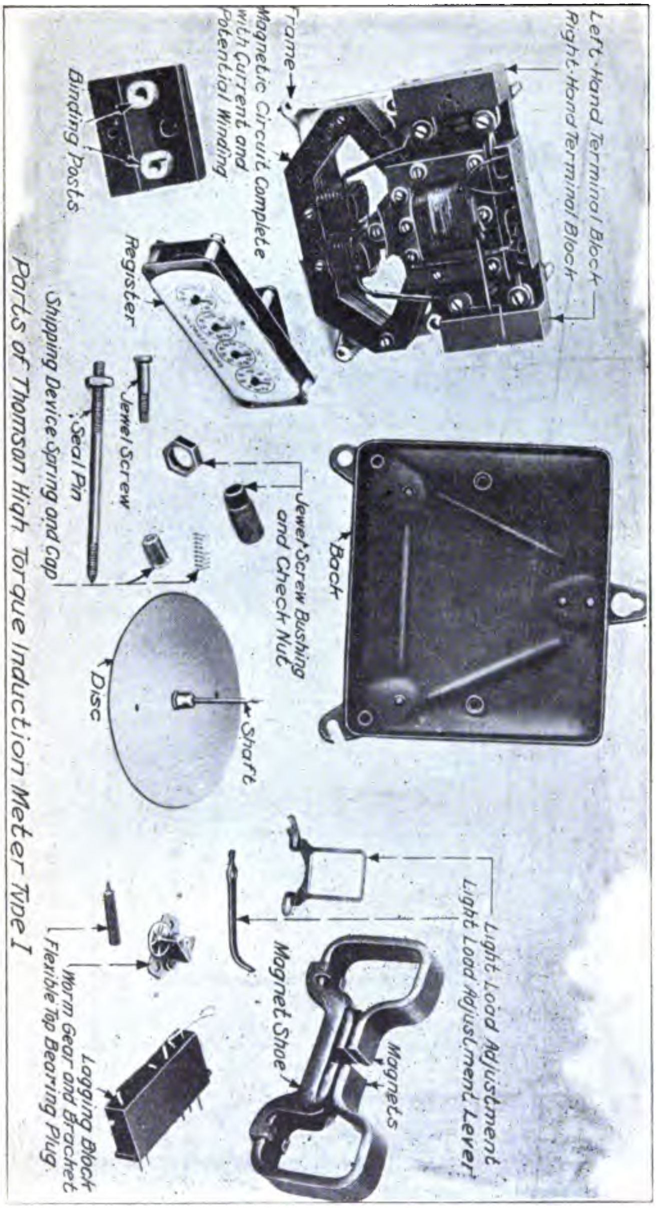


Fig. 21.

The light load adjustment clip of the General Electric induction meter is shown at A in Fig. 21, and consists of a rectangular copper conductor which acts as a short-circuited loop, being so mounted that it can be shifted in a plane at right angles to the axis of the potential pole. This short-circuited turn has an e.m.f.

induced in it, by the flux from the potential pole tip, which in turn sets up a current that is practically in phase with this e.m.f.; the current produces a magnetic field which is out of phase with the flux from the potential pole. This flux from the light load adjusting coil reacts with the main flux from the potential pole tip and thus produces a turning effort which acts upon the meter disc. The amount of this turning effort can be varied by simply shifting the short-circuited turn, so that there will be a mechanical as well as a time phase displacement between the flux from it and that produced by the potential pole. The illustrations in Fig. 22 (a and b) shows clearly the construction of the General Electric Company's single phase induction meter for ordinary house use, from which a general idea may be had of the parts entering into the construction of a typical induction watthour meter.

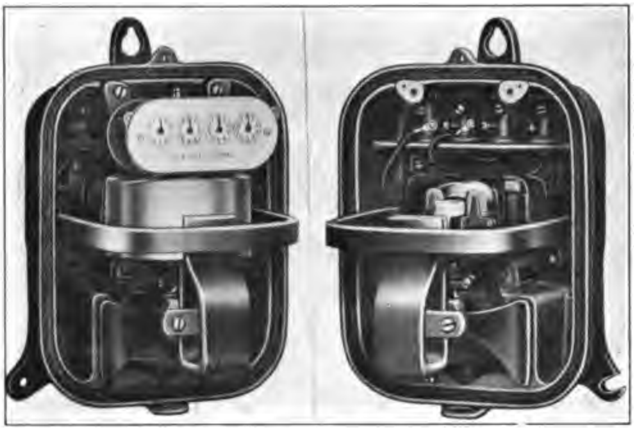
Fig. 22a.



Parts of Thomson High Torque Induction Meter Type I

Fig. 22b.

The light load adjusting device of the Fort Wayne induction meter consists of a laminated iron arm which forms part of the potential pole, and upon which is mounted the short-circuited coils. The position of this arm can be shifted, the effect being similar to that described for the General Electric meter. Figure 23 is an illustration of the Fort Wayne company's single


a Fig. 23. b

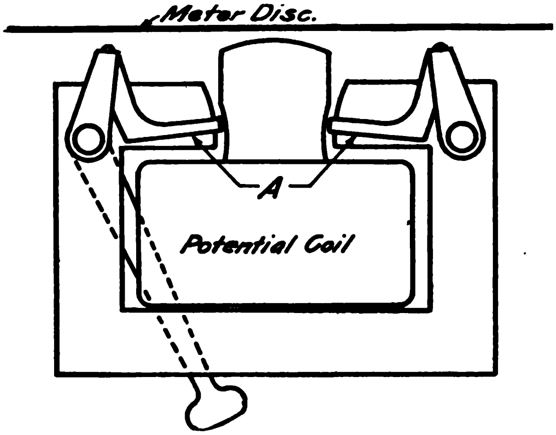


Fig. 24.

phase meter, and, as will be noted, the disc has a peculiar "cup-shaped" form. The illustration at (b) shows the ease with which the disc may be removed without disturbing other parts of the meter.

The light load adjusting device of the Westinghouse induction meter consists of two adjustable short-circuited turns so mounted that they may be rotated

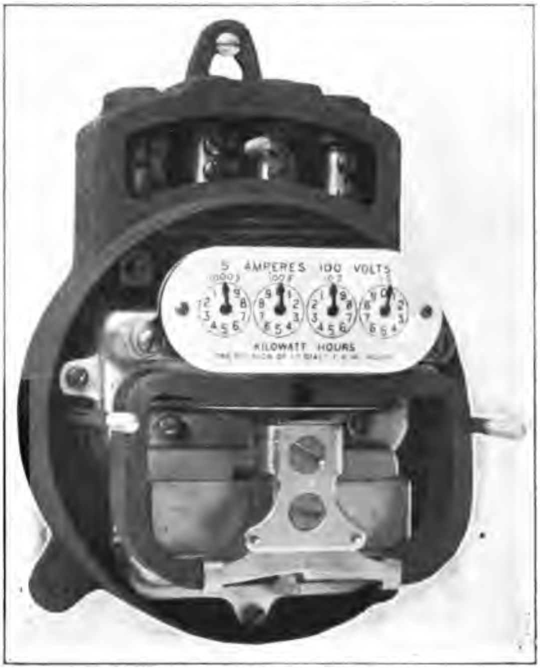


Fig. 25a.

through a small angle. One side of each of these short-circuited turns is in an air-gap in the magnetic circuit of the potential winding and by partially rotating the turn it can be made to enclose more or less lines of magnetism, as can be readily seen from the diagram in Fig. 24 at A. The lines of magnetism, in passing through the short-circuited turns, induce currents therein, which currents set up an auxiliary field. This auxiliary field is out of phase with the main field from the potential pole, and the two, acting in conjunction, produce a torque on the meter disc, the amount of which can be varied by moving the short-circuited turns so that they will embrace more or less of the flux passing through the air-gap. In Fig. 25 (a and b) are shown two views of the single phase type of induction meter as manufactured by the Westinghouse company.

The object of the light load adjusting device is to produce a torque from the potential circuit alone (independent of the load on the meter), the magnitude of which will be just enough to overcome the friction of the meter, therefore rendering it accurate on light loads.

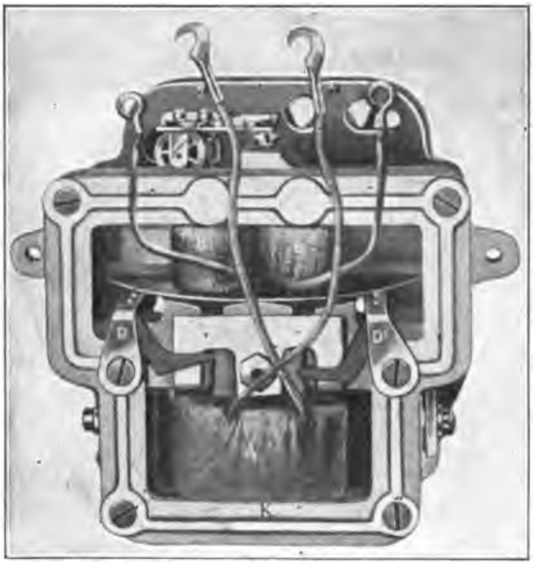


Fig. 25b

Creeping.

If the light load adjustment is set so as to exert a torque greater than is actually necessary to overcome the friction it will cause "creeping" on no load.

Creeping will also result if the light load adjustment is properly set for operation at normal voltage and then the meter installed on a circuit where the voltage is considerably above the normal voltage rating of the meter. A higher voltage will produce a higher flux from the potential pole, which in turn will induce a higher current in the light load adjusting coil, and this higher current and higher flux will mutually react and produce a higher no load torque, thereby causing the meter to creep.

Effect of Frequency Variations.

When an induction meter is operated on a frequency other than that for which it is adjusted, the lagging coil will no longer set up just the necessary flux to bring the resultant flux from the potential pole exactly 90 degrees behind the impressed e.m.f.; it will either be ahead or behind this correct 90 degree position, depending upon whether the frequency is below or above the normal value. Errors from this source will be inappreciable so long as the frequency is within 10% (approximately) of the normal value.

It is at the present time the practice of the leading meter manufacturers to design their 125 cycle and their 133 cycle meters so that by a simple connection or adjustment, which can be easily made, they may be used with accuracy on 60 cycle circuits. This is on account of the fact that 60 cycles is the standard lighting and power frequency, and as the majority of the higher frequency plants will sooner or later be changed over to 60 cycles, it will evidently be a great saving to them if they can use their old meters rather than have to purchase new 60 cycle meters when such a change may be made. Meters so constructed are known as "double lagged" meters, since they are lagged at the factory for two different frequencies.

The effect of a frequency other than normal can be best shown by reference to the diagram shown in Fig. 26, in which

OE=the impressed e.m.f.,
OI=current in potential coil at normal frequency,
OI_1=current in potential coil at low frequency,
OI_2=current in potential coil at high frequency,

OI_L, OI_{L-1} and OI_{L-2} = the currents in the lagging coil for these different frequencies.

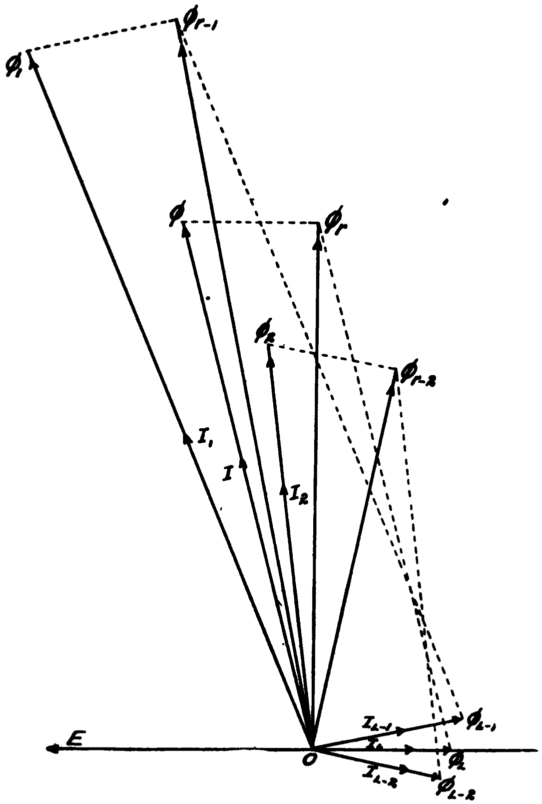


Fig. 26.

Now suppose that the meter is properly lagged for a frequency, f, the current in the potential winding being OI, and the flux therefrom being Oϕ. The current in the lagging coil will be OI_L, and the flux therefrom will be $O\phi_L$; these two fluxes, $O\phi$ and $O\phi_L$ combine to produce the resultant flux $O\phi R$, which is exactly 90 degrees behind the impressed e.m.f. Now suppose that the meter is used on a frequency, f_1, which is below normal. With a lower frequency the flux set up by the potential coil will be greater, as the rate of change of flux must remain the same. The magnetizing current, OI_1, will therefore be greater, the core loss and the RI^2 losses will be higher, so that there will be a larger energy component of the current, and it will therefore not lag by as great an angle as with normal frequency; the current OI_1 sets up the flux $O\phi_1$, which represents the condition for a frequency below normal. The flux, $O\phi_1$, combining with the flux $O\phi_{L-1}$, set up by the lagging coil at the lower frequency, produces the resultant flux $O\phi R_{-1}$, which does not lag to the 90 degree position, and in order that it be made to lag to the correct 90 degree position, it is necessary for the lag coil to set up a greater flux than $O\phi_{L-1}$, which can be accomplished by relagging the meter for this lower frequency, f_1.

Now in the case of a higher frequency, f_2, the current in the potential winding is represented by OI_2, and the corresponding flux by $O\phi_2$. Both the core loss and the RI^2 losses in the potential winding will now be less than in the initial case, the energy component will therefore be less, and the flux will lag more nearly to the correct 90 degree position. The flux, $O\phi_{L2}$, now set up by the lagging coil, will combine with the flux $O\phi_2$, producing the resultant flux $O\phi R_{-2}$, which lags too much, being beyond the 90 degree position. In order for the resultant flux to lag to the correct position, it will therefore be necessary for the lagging coil to set up a flux less than $O\phi_{L-2}$; in other words, the meter would have to be relagged for this higher frequency, f_2.

Obviously, for power factors other than unity, serious errors would be introduced by using a meter adjusted for a frequency different from that of the circuit on which it operates; the meter might either run fast or slow, depending upon whether it is adjusted for a higher or lower frequency than that of the circuit on which it operates, and upon whether the current is lagging or leading.

The effect of a frequency above normal will be to make the meter run fast on lagging currents and slow on leading currents; a frequency below normal will cause the meter to run slow on lagging currents and fast on leading currents. For unity power factor there would also be an error introduced, although it would not be so pronounced as in the case of power factors other than unity. In this case only that component of the flux from the potential pole which is in the correct 90 degree position will be effective, so that the phase displacement of the resultant flux will tend to make the meter run slow on any frequency other than that for which the meter is adjusted. The values of the resultant fluxes are not strictly proportional to the frequencies, however, since the component supplied by the lagging coil is not proportional to the frequency and its angular relation to the main component is different for the different frequencies; also for lower frequencies, the energy component of the voltage is greater and the reactive component is less, due to the increased shunt current which tends to make the meter run slow, and vice versa for higher frequencies.

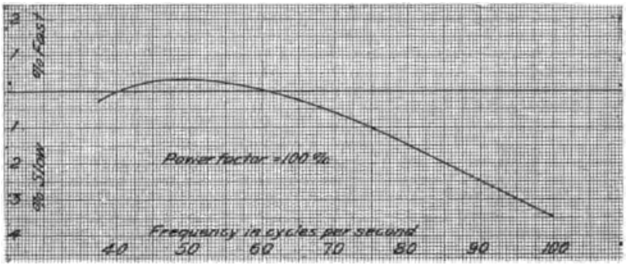


Fig. 27.

The currents induced in the meter disc by the current coils should be directly proportional to the frequency, but due to the demagnetizing effect of these currents on the current coil poles, this condition is not strictly fulfilled, which causes the meter to have a tendency to run slow on frequencies above normal and fast on frequencies below normal.

The resultant effect of the different disturbing factors above mentioned will affect the meter to an extent dependent largely upon the design.

Figure 27 is a curve showing the accuracy of a standard make of induction meter on different frequencies at unity power factor, and Fig. 28 shows the load and voltage curves of a standard 5 ampere induction meter operating at normal frequency.

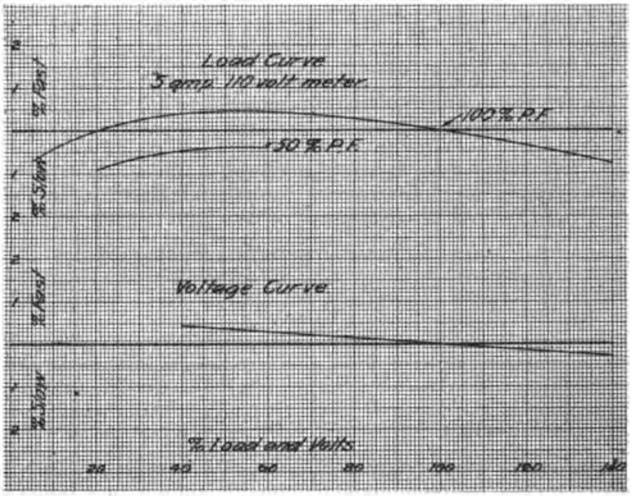


Fig. 28.

Connections of Single Phase Meters.

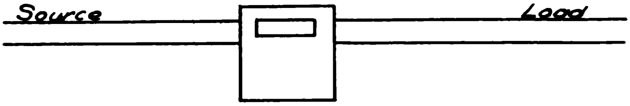


Fig. 29.

Fig. 29 shows the diagram of connections for a single phase watt-hour meter when used on a single phase two wire circuit.

Fig. 30 shows the connections of two single phase meters connected so as to register the power flowing in a single phase three wire circuit, and Fig. 31 shows one three wire single phase meter connected for the same conditions. The three wire meter in effect is really two meters with but one disc and one potential coil, but with a current coil in each side of the line.

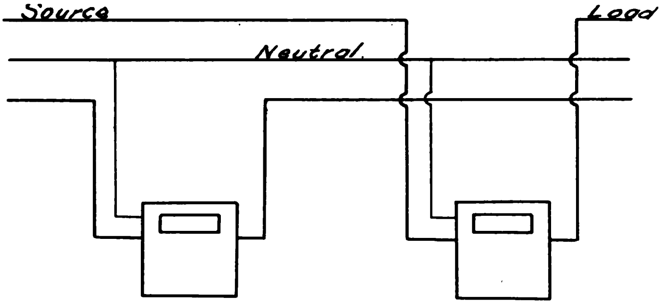


Fig. 30.

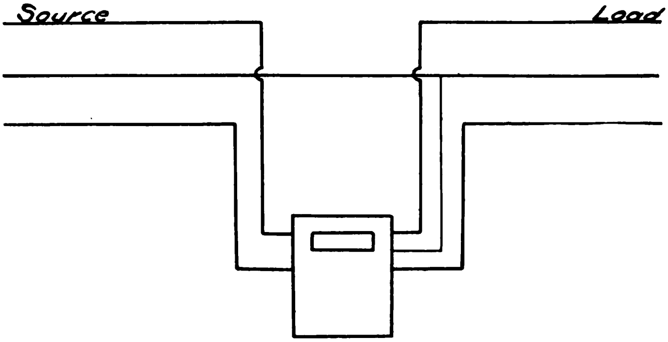


Fig. 31.

The fact that the three wire meter has but one potential winding will cause an error in its registration if the voltage between each line and the neutral is not the same. The polyphase meter can also be used as a single phase three wire meter, and is not subject to the error just mentioned, but owing to its greater cost, it is seldom used for this purpose.

One single phase two wire meter can also be used to register the power flowing in a single phase three wire system by using it in connection with a special "three wire" current transformer. Such a transformer has two primary windings and one secondary winding. The two primary windings are connected respectively in series with each side of the line, the current in the secondary being proportional to the vector sum of the currents in the two primaries. The connections of a single phase meter when used with such a transformer are shown in Fig. 32.

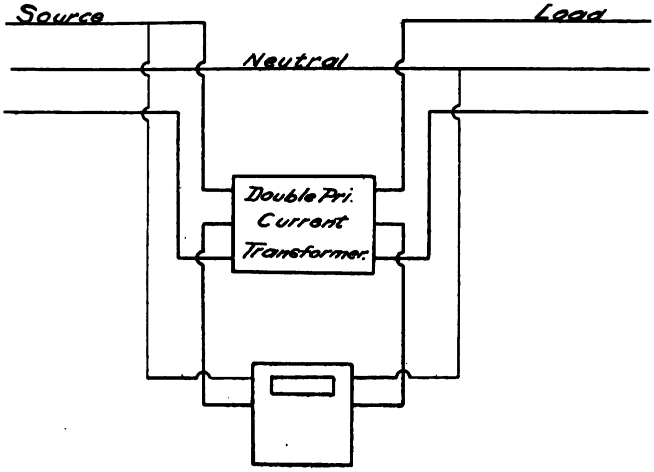


Fig. 32.

Single Phase Meters on Polyphase Circuits.

Two single phase meters may be used to register the power being supplied by either a two phase or a three phase system. For a two phase four wire system, one meter should be connected in each phase as shown in Fig. 33, and when so connected, each meter will register the power in its respective phase; the algebraic sum of the readings of the two meters will then be the total power supplied by the two phase system.

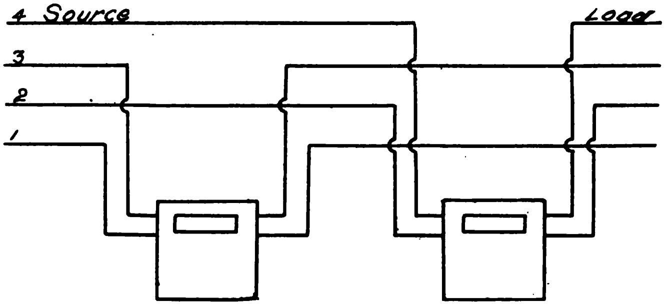


Fig. 33.

In the, case of a three phase system, the two single phase meters should be connected as shown in

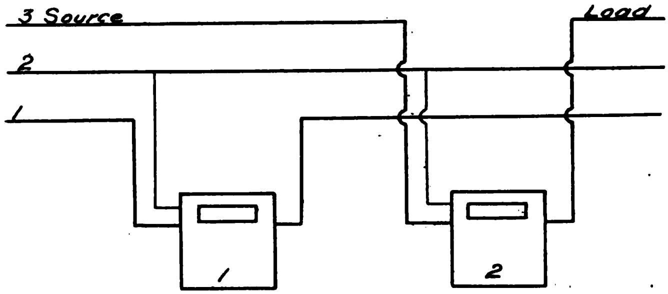


Fig. 34.

Fig. 34. (Similar connections for potential and current transformers are shown in the appendix, Figs. 33a, 34a.) The action of the two meters thus connected can best be explained by reference to the vector diagram, Fig. 35, in which AC, CB and AB represent the

voltages between the phases 2 and 1, 1 and 3, and 3 and 2 respectively; also let CO, BO and AO represent the currents in the phases 1, 3 and 2 respectively, for the condition of unity power factor, and C′O, B′O and A′O the currents for a power factor other than unity.

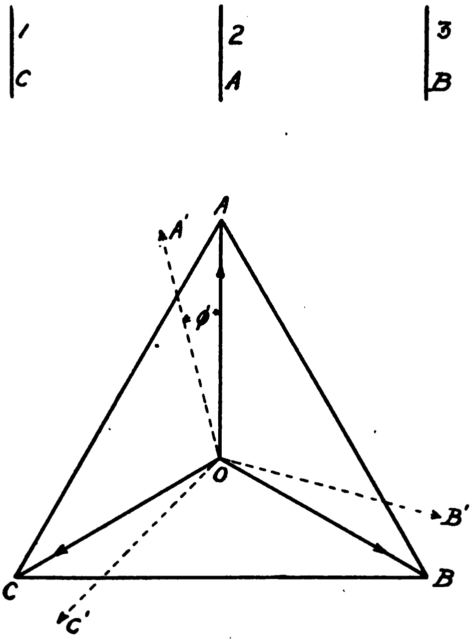


Fig. 35.

We will first consider the case of a balanced system. In this case let e represent the e.m.f. between a line and neutral, then $e = \frac{E}{\sqrt{3}}$, when E is the voltage between lines; also let I represent the current per phase in a balanced system. A three phase system may be considered as consisting of three single phase systems with the neutral as a common return; the voltages of each of the single phase systems being represented by e, and the current by I. The power in each single phase system will be $= (e\,I) \cos \theta$, where θ is the angle by which the current is displaced in phase from the voltage, (Fig. 35); the power in the three phase system will therefore be the sum of the power in the three equivalent single phase systems, or, numerically,

$$P = 3\,e\,I \cos \theta\text{; and since } e = \frac{E}{\sqrt{3}},$$

we have $P = \sqrt{3}\,E\,I \cos \theta$, which is the fundamental equation for the power flowing in a three phase system.

The two meters connected as shown in Fig. 34 will each have a current I flowing through it, and a voltage E impressed upon its potential winding. In meter No. 1, the current is represented by the line C'O (Fig. 35), and the voltage by CA; and in meter No. 2 the current is represented by B'O, and the voltage by AB; the current being represented as being out of phase by the angle θ. The angle OCA = angle OBA = 30 degrees, which is the angular displacement between the impressed voltage and the line current for unity power factor. For power factors other than unity, this angular displacement is equal to 30 degrees plus or minus the angle θ, and as can be readily seen from the diagram it will be $(30° - \theta)$ for one meter and $(30° + \theta)$ for the other meter.

The power p', registered by one meter will therefore be

$p' = E\,I \cos (30° + \theta)$, and the power p'', registered by the other meter will be $p'' = E\,I \cos (30° - \theta)$, from which

$$p' + p'' = EI \cos (30° + \theta) + EI \cos (30° - \theta)$$
$$= EI\,[\cos (30° + \theta) + \cos (30° - \theta)]$$
$$= EI\,[2 \cos (30° \cos \theta)]\text{ and since } \cos 30° = 1/2\sqrt{3},$$

we have

$p' + p'' = EI\,\sqrt{3} \cos \theta$, which, as shown above, is the equation for the power flowing in a three phase system. It is therefore seen that two single phase meters will register correctly the power in a balanced three phase system.

An unbalanced three phase system may be considered as consisting of a balanced system with the addition of an unbalancing component of either current, voltage or both. When using two single phase meters on an unbalanced three phase system, the unbalanced component will be taken care of as follows:

Suppose that in addition to the balanced current, there is a current flowing between the phases 2 and 3 (Fig. 35), or between 2 and 1; this current would flow either through meter No. 1 or meter No. 2, and as the meter through which it would flow has impressed upon it the voltage of the phases between which this current is flowing, the meter would register the power correctly. In the case of an unbalanced current passing between phases 3 and 1, such current would flow through both meters, and if this unbalanced current is in phase with the voltage BC, between phases 3 and 1, it will be 60° out of phase with the voltage impressed upon each meter, and as the cosine of 60° is 1/2, the correct amount of power will be registered, one-half being registered by each meter. If this current is not in phase with BC, it will be out of phase more than 60° in one meter, and less than 60° in the other meter; the correct amount of power will still be registered, but it will not still be equally divided between the two meters. The angle by which this unbalanced current will be out of phase in one meter will be $(60° + \theta)$, and in the other it will be $(60° - \theta)$, where θ is the angle of displacement between the unbalanced current and the voltage BC. The power registered by one meter will be $= E\,i \cos(60° + \theta)$, where $i =$ the unbalanced current, and that registered by the other would be $= E\,i \cos(60° - \theta)$, and the total **unbalanced** power would be,

$$p = E\,i\cos(60^\circ + \theta) + E\,i\cos(60^\circ - \theta),$$
$$= E\,i\,(2\cos 60^\circ \cos\theta), \text{and since } \cos 60^\circ = 1/2,$$

we have $p = E\,i\cos\theta$, which shows that the power would be correctly registered in the case of an unbalanced current.

Unbalanced voltages would be taken care of in a similar manner. An unbalanced voltage across phases 1 and 2, or across 2 and 3, would directly affect the potential winding of one or the other of the single phase meters. An unbalancing of the voltage across phases 3 and 1 would affect both meters by distorting the voltage triangle so that the power transmitted would still be correctly registered.

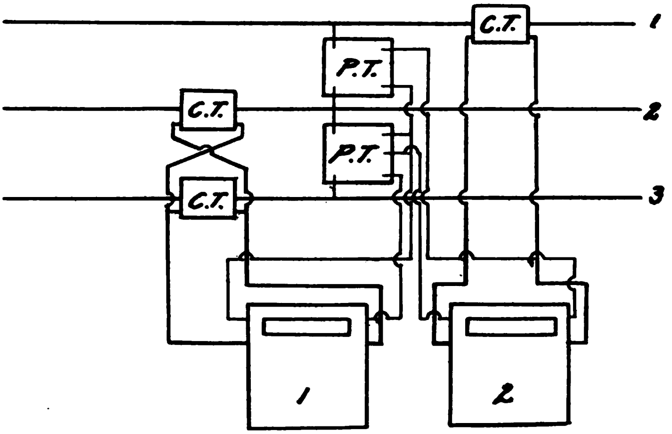


Fig. 36.

Another method of connecting two single phase meters to register the power in a three phase system in conjunction with current and potential transformers is shown in Fig. 36; the relations of the currents and voltages being shown in the vector diagram, Fig. 37. Let I, I′ and I″ represent the currents in the three legs of a three phase system; E being the voltage between lines and e the voltage between any line and neutral. Also let θ, θ', and θ'' represent the angles by which the currents are displaced from the position of unity power factor; we will assume the voltage to be balanced, since this makes the explanation somewhat simpler. The true power is $P = e\,I \cos\theta + e\,I' \cos\theta' + e\,I'' \cos\theta''$. Meter No. 1 has currents I and I' flowing through its winding (that is, the resultant of these currents), and the voltage, E, CA, impressed upon it; it is used with a multiplier of 1/2.

Meter No. 2 has the current I'' flowing through it, and the voltage Bn, impressed upon it; Bn = (3/2) e. Let P represent the total power, P' the power registered by meter No. 1 and P'' the power registered by meter No. 2,

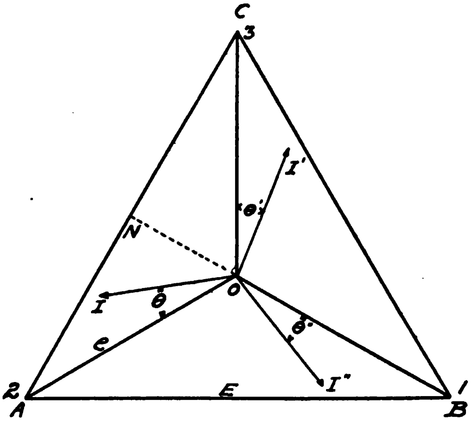


Fig. 37.

$$P' = EI' \cos(30^\circ - \theta') + EI \cos(30^\circ + \theta).$$

$$P'' = \frac{3}{2} e\,I'' \cos\theta''.$$

$$P = \frac{P'}{2} + P'$$

$$= \frac{EI' \cos(30 - \theta') + EI \cos(30 + \theta)}{2} + \frac{3}{2} eI'' \cos\theta''$$

and $\cos(30^\circ - \theta') = \cos 30^\circ \cos\theta' + \sin 30^\circ \sin\theta'$
$\cos(30^\circ + \theta) = \cos 30^\circ \cos\theta - \sin 30^\circ \sin\theta$;

also, $\cos 30^\circ = \frac{\sqrt{3}}{2}$, $\sin 30^\circ = \frac{1}{2}$, and $e = \frac{E}{\sqrt{3}}$

$$\text{whence } P = E\left[\frac{I\sqrt{3}}{2}\cos\theta - \frac{I\sin\theta}{2} + \frac{I'\sqrt{3}}{2}\cos\theta' + \frac{I'}{2}\sin\theta'\right]\frac{1}{2} + \frac{E\sqrt{3}}{2}\cos\theta'' I''$$

$$= \frac{\sqrt{3}\,E}{4}(I\cos\theta + I'\cos\theta') + \frac{E}{4}(I'\sin\theta' - I\sin\theta) + \frac{E\sqrt{3}}{2}\cos\theta'' I''.$$

The vector sum of the currents in a three phase three wire system is zero, therefore $I''\cos\theta'' = I\cos(60 - \theta) + I'\cos(60 + \theta')$, reducing this we get

$I'\sin\theta' - I\sin\theta = \frac{2}{\sqrt{3}}[\frac{1}{2}(I\cos\theta + I'\cos\theta') - I''\cos\theta'',]$ substituting this for $I'\sin\theta - I\sin\theta$ in the above and substituting $\sqrt{3}\,e$ for E, we derive,

$$P = \frac{3}{4}e(I\cos\theta + I'\cos\theta') + \frac{e}{2}\left(\frac{I}{2}\cos\theta + \frac{I'}{2}\cos\theta' - I''\cos\theta''\right) + \frac{3e}{2}I''\cos\theta''.$$

whence $P = e\,I\cos\theta + e\,I'\cos\theta' + e\,I''\cos\theta''$.

The particular feature of this connection is that it gives an indication of how well the system is balanced; if the system is perfectly balanced the two meters will register the same power, taking into consideration, of course, the multiplier of 1/2. This is true with the connection previously described and most often used, only when the power factor is unity.

If the system is perfectly balanced, either of the meters can be relied upon to record the total power, regardless of the value of the power factor, in which case the dials of meter No. 1 would be read without a multiplier, and meter No. 2 would have a dial multiplier of 2.

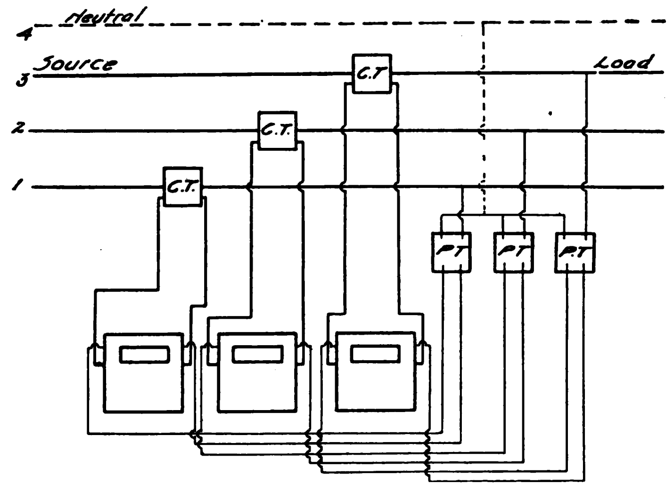


Fig. 38.

In Fig. 38 is shown the connections of three single phase meters for measuring the power in three phase, three and four wire systems. The three phase circuit is metered in this case simply as three single phase circuits, the current in each phase being the current in one of the single phase circuits, and the voltage of each single phase circuit being the voltage from the corresponding line to the neutral. The sum of the readings of the three meters will be the kilowatt-hours supplied by the three phase system.

The advantage of this connection for the three wire system is that the meters operate under better power factor conditions than with the usual two meter method. With this method the current and e.m.f. of each meter will be in phase when the power factor of the load being metered is unity, while with the two meter method the current and e.m.f. are 30° out of phase.

Figure 38 (a) shows another method of connecting the potential transformers for measuring the power flowing in a three phase three wire system by means of three single phase meters. This connection, with certain primary voltages, permits the use of standard ratio potential transformers, where the connection shown in Fig. 38 will require ratios other than the standard. This method is especially applicable to 2300 volt circuits, the standard potential transformer used in this case would be rated 2200 volts primary, and 110/122 volts secondary, the higher secondary voltage (122) being used as is indicated in the figure. With a 2300 volt primary, a secondary voltage of approximately 220 volts would be obtained from the potential transformers, thereby permitting the use of standard 220 volt meters. When meters are used in this manner, a multiplying factor, $\frac{R \times R'}{3}$, is

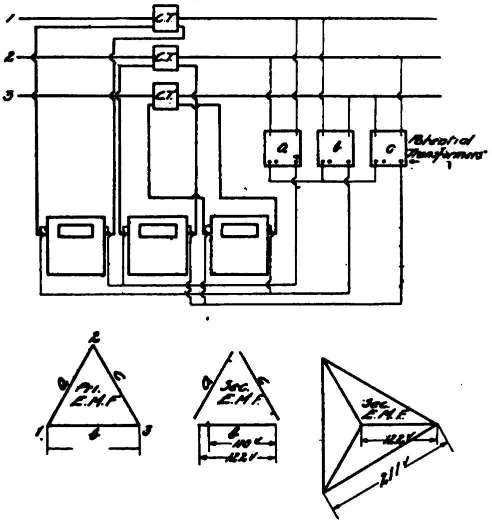


Fig. 38a.

employed in obtaining the total reading, in which R = the ratio of the current transformers and R' = ratio of the potential transformers $(= \frac{2200}{122})$.

Determination of Power Factor by Means of Two Single Phase Meters.

The method of metering with two single phase meters on a balanced three phase system has an advantage over the polyphase meter when it is desired to obtain the average power factor of the load, which can be done by applying the following formula:

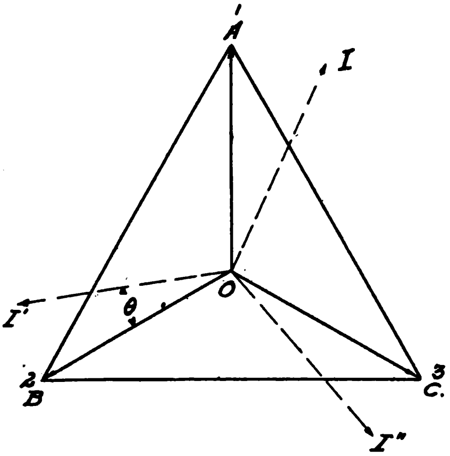


Fig. 38b.

Average Power Factor =

$$\frac{P' + P''}{2\sqrt{(P')^2 - (P' \times P'') + (P'')^2}}$$

where P' and P'' represent the readings of the two single phase meters. The deduction of this formula is as follows: In the vector diagram, Fig. 38 (b) AB, AC and BC represent the voltages between the phases of a three phase circuit, and OI, OI′ and OI″ represent the currents in the legs 1, 2 and 3 respectively, and which are displaced from the position of unity power factor by the angle θ. Now suppose that the current coil of meter No. 1 is connected in leg No. 2, and that its potential coil is connected across AB; also that the current coil of meter No. 2 is connected in leg No. 3 and its potential coil across AC. Then the power, P′, being registered by meter No. 1 will be $=$ AB. OI′ cos ϕ, where ϕ is the angle between AB and $OI' = (30^\circ + \theta)$, θ being the angle of current displacement. The angle OBA is of course 30°. Denoting the voltage AB by E, and the current OI′ by I, we have $P' = EI \cos (30 + \theta)$ and similarly, the power being registered by meter No. 2 will be $P'' = EI \cos (30 - \theta)$, (assuming the system to be balanced). Then by trigonometry we have,

$$\cos (30 + \theta) = \cos 30 \cos \theta - \sin 30 \sin \theta$$

$$\cos (30 - \theta) = \cos 30 \cos \theta + \sin 30 \sin \theta$$

But $\cos 30^\circ = 1/2 \sqrt{3}$, and $\sin 30^\circ = 1/2$,

Therefore $\cos (30 + \theta) = 1/2 \sqrt{3} \cos \theta - 1/2 \sin \theta$

and $\cos (30 - \theta) = 1/2 \sqrt{3} \cos \theta + 1/2 \sin \theta$

Substituting these values in the above equations for P′ and P″ we have:

$$P' = EI\left(\tfrac{1}{2}\sqrt{3} \cos \theta - \tfrac{1}{2} \sin \theta\right), \text{ hence}$$

$$EI = \frac{P'}{\left(\tfrac{1}{2}\sqrt{3} \cos \theta - \tfrac{1}{2} \sin \theta\right)}$$

$$P'' = EI\left(\tfrac{1}{2}\sqrt{3} \cos \theta + \tfrac{1}{2} \sin \theta\right), \text{ hence}$$

$$EI = \frac{P''}{\left(\tfrac{1}{2}\sqrt{3} \cos \theta + \tfrac{1}{2} \sin \theta\right)} \text{ or since } EI = EI,$$

we have

$$\frac{P'}{\tfrac{1}{2}\sqrt{3} \cos \theta - \tfrac{1}{2} \sin \theta} = \frac{P''}{\tfrac{1}{2}\sqrt{3} \cos \theta + \tfrac{1}{2} \sin \theta}$$

By trigonometry, $\sin \theta = \sqrt{1 - \cos^2\theta}$, and substituting this value

$$\sqrt{3}\,P' \cos\theta + P' \sqrt{1 - \cos^2\theta} = P'' \sqrt{3}$$

$$\cos\theta - P'' \sqrt{1 - \cos^2\theta},\ \sqrt{1 - \cos^2\theta}\ (P' + P'')$$

$$= (P'' - P')\sqrt{3}\cos\theta.$$

Squaring and transposing, we have,

$$\cos^2\theta\,[\,4\,(P')^2 - 4\,P'\,P'' + 4\,(P'')^2\,] = (P' + P'')^2,$$

Whence

$$\cos\theta = \frac{P' + P''}{2\sqrt{(P')^2 - P'\,P'' + (P'')^2}} = \text{average power factor}$$

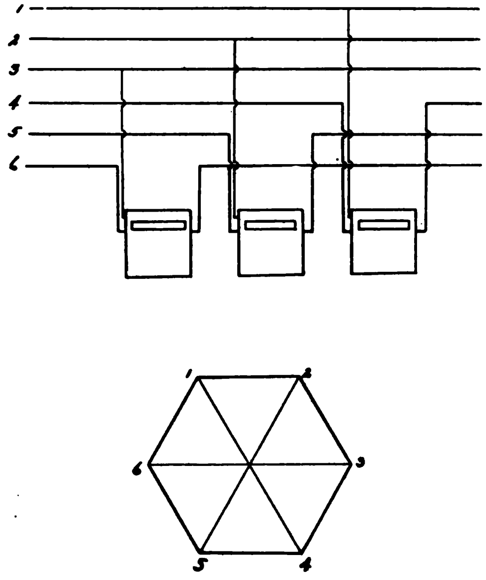


Fig. 39.

The true instantaneous power factor can also be determined by this method, using two indicating wattmeters.

Single Phase Meters for Six Phase Circuits.

Three single phase meters can be used for measuring the power in a six phase system by connecting them as shown in Fig. 39.

Polyphase Meters.

The polyphase induction watthour meter for use on either a two or three phase system consists essentially of two single phase meter elements mounted one above the other on the same shaft, and having but one register. The principle of operation is identically the same as that previously explained for two single phase meters, except that in the case of the two single phase meters, the algebraic sum of the two registers is taken to obtain the total power, while in the case of the polyphase meter this is automatically accomplished by having the two discs connected to one shaft. The polyphase meter has the advantage of being easy to read and install.

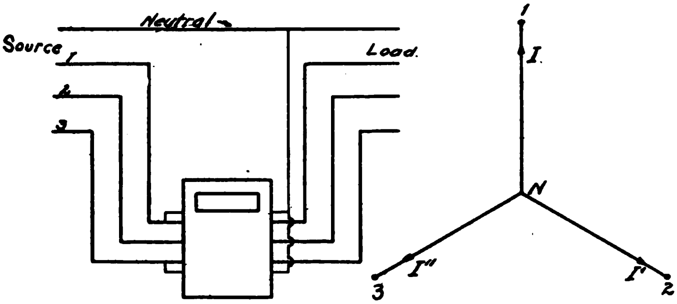


Fig. 40.

The polyphase meter for use on three phase four wire systems when used without current transformers is of somewhat different construction from the meter used on three phase three wire, or on two phase systems. In the three phase four wire meter without current transformers, it is necessary to have a current winding in the meter for each phase. These windings are arranged on the two elements in such a manner that the current in one phase passes through a winding on each element; the current in each of the other two phases passing through a winding on one element. Fig. 40 shows the vector diagram and also the diagram of connections of this type of meter, in which I, I′ and I″ represent the currents in phases 1, 2 and 3 respectively, and 1-n, 2-n and 3-n represent the voltages between the legs 1, 2 and 3 and the neutral wire, n. One element of the meter has the voltage 3-n impressed upon its potential winding, and the current I″ passing through one set of current coils, and the current I′ passing through the other set of current coils. The other element has the voltage 1-n impressed upon its potential winding, and the current, I passing through one set of current coils, and the current I′ passing through the other set.

A three phase four wire system is, in effect, three single phase systems, the current in each system being the current in the corresponding phase, and the voltage of each system being the voltage between the corresponding phase and the neutral.

With the connections described above, the power being transmitted by each of the two single phase systems, 3-n and 1-n will be correctly recorded by the meter for both unity power factor and for power factors other than unity, as each element of the meter will act as a single phase meter in recording this power. The power being transmitted by single phase, 2-n will be recorded partly by one meter element and partly by the other. The current I′ passes through both meter elements, the connections to its coils being reversed so that for unity power factor it is 60° out of phase with the voltage impressed on each element. (If these coils are not reversed the current, I′ will pass through the meter 120° out of phase with the voltages impressed on the two elements and will subtract instead of adding the power in phase 2-n.)

Since the cosine of $60° = 1/2$, one-half of the power will be recorded by each element. For power factors other than unity, one element will record more than half, and the other element will record less than half the power being transmitted; the sum of the power recorded by both elements will be equal to the total power.

When current transformers are used with three phase four wire meters, the standard polyphase meter as used on three phase three wire circuits may be used, the current transformers being so connected that the resultant current of phases 3 and 2 passes through the current coils of one element, the voltage, 3-n being impressed on this element; the resultant current of phases 1 and 2 passes through the current coil of the other element which has the voltage 1-n impressed upon it.

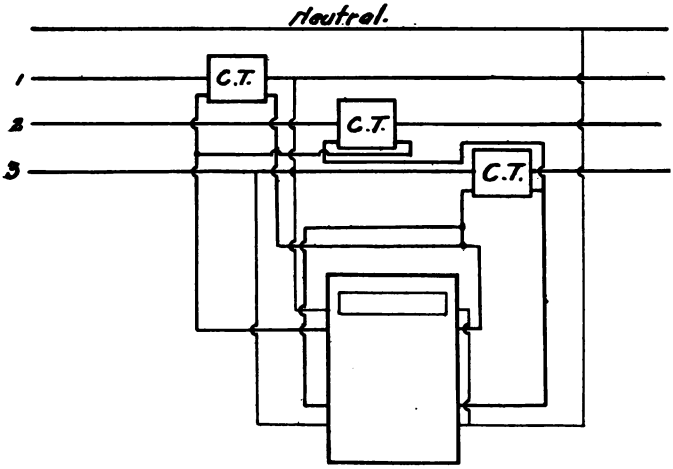


Fig. 41.

The action of this type of meter is the same as just described for the meter without current transformers. In the latter case, two sets of current coils are used on each meter element, the resultant effect of the currents in these two sets of coils being the same as the resultant of the currents from two current transformers passing through one set of current coils.

Fig. 41 shows the proper connections for a polyphase meter when used on a three phase four wire system in conjunction with current transformers.

Adjustment of Elements.

Polyphase meters should be provided with some means of adjusting the torque of one of the elements without disturbing the other. This is necessary because there is only one retarding system which is common to both elements, and it is therefore necessary that some means be provided so that the two electrical elements may be adjusted to give the same torque when the same amount of power is passing through each. This adjustment is readily accomplished by changing the number of turns on the potential winding of one of the elements. By this means, the torque of that particular element can be adjusted to be the same as that of the other element. This is done in some meters by bringing out a number of taps from the potential winding, having a very few number of turns between taps, so that a fine adjustment can be accomplished.

Other meters employ what is known as a "balance loop," which is a short-circuited turn whose position can be so changed that it will introduce more or less reluctance in the path of that portion of the flux from the potential winding which does not pass through the meter disc. Increasing this reluctance will cause more of the flux to pass through the meter disc, while decreasing it will cause less flux to pass through the disc. After adjusting the "balance loop" the meter should be "re-lagged."

The balance between the elements of a polyphase meter can also be altered by changing the air gap between the potential and the current coil poles of one element; this can be accomplished by loosening the screws and prying the poles further apart or by using a light wooden mallet to drive them closer together. The adjustment obtained by this means is necessarily very rough, but it is sometimes useful (usually when putting a new potential coil in place) to bring the elements within the range of adjustment provided by the manufacturer.

Interference of Elements.

Polyphase meters are subject to one source of error from which two single phase meters used on polyphase circuits are entirely free, that being the "interference of elements," which is due to the interference or reaction of the magnetic fields of one element with the fields of the other, and in some cases it introduces errors amounting to as much as 4% or 5%. For this reason the elements should not be placed too close together. In a well designed meter operating near unity power factor, the error from this source should never amount to more than 0.5%.

Polyphase Meters on Six Phase Circuits.

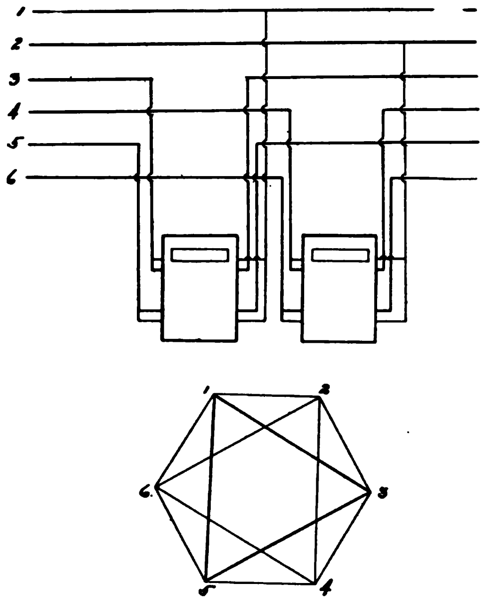


Fig. 42.

Fig. 42 shows the proper connections of two polyphase meters when used to measure the power flowing in a six phase system.

Metering High Potential Circuits.

When meters are used on high potential circuits, the secondaries of both the potential and the current transformers should be solidly grounded. This is not only a precaution for the safety of those who have to read and test the meter, but it also prevents undue strain between the windings of the meter. Both the potential and the current transformers act as condensers, and so do the windings of the meter themselves. The voltage of the system is thus impressed across several condensers in series, the strain across each condenser being inversely proportional to its electro-static capacity. It is possible for the strain thus impressed to reach a value which will puncture the insulation from the winding to the core.

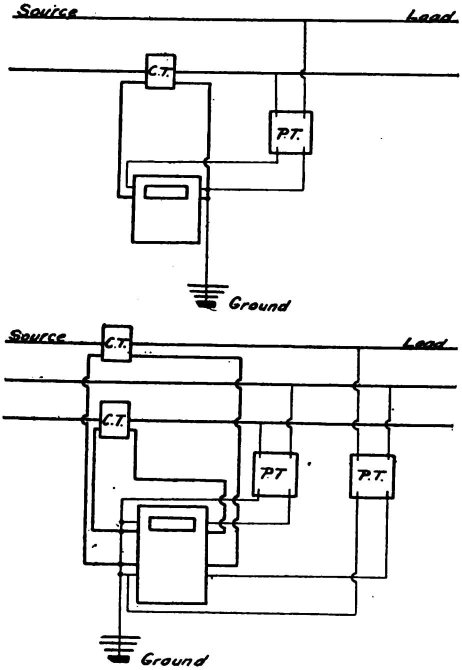


Fig. 43.

Fig. 43 shows the connections for both a single and a polyphase meter when used with current and potential transformers, showing the ground connection to be made when used on high potential circuits.

When metering the high tension side of a "Y" connected three phase system, the current transformers can be relieved of a great part of the high tension strain by connecting them between the power transformers and the neutral or "Y" point. This will also protect the current transformers from lightning and high potential surges, as each current transformer will have a power transformer between itself and the line.

Current and potential transformers used with watt-hour meters should never be operated under the condition of overloads, and it is best to have them operate considerably underloaded. Overloading the transformers will cause the meters to run slow.

Current transformers are usually rated at so many watts, for instance, 40 watts. The sum of the volt-amperes taken by all the meter coils in series with such a transformer plus the volt-amperes consumed in the leads to the meters should never exceed this amount and should preferably be less.

Potential transformers are usually rated at from 10 to 200 watts. The total load in volt-amperes should never exceed the rating and where a high degree of accuracy is required the total load should be considerably less than the rating.

In making connections of polyphase watthour meters care should be taken to see that the meter is connected exactly in accordance with the diagram furnished by the manufacturer; if this is not done, the meter may be connected so that it will run in the proper direction, but the interference between elements will be high; this will be the case if both the current and potential connections of one element are reversed.

CHAPTER IV.

THE COMMUTATING TYPE OF WATTHOUR METER.

During the past few years the commutating type of watthour meter has practically been superseded by the induction type for use on alternating current systems, and at the present time its use is principally in connection with direct current work.

The commutating meter (as well as other types) is in reality a direct connected motor-generator, the motor being of the shunt type, having its armature connected in multiple (or parallel) with the source of supply and with its field coils in series with the load to be measured. The revolving aluminum (formerly copper) disc and the retarding magnets comprise the generator. As the disc D, Fig. 44, revolves between the jaws of the retarding magnets M, it cuts the lines of magnetic force, thus producing "Foucault" or "eddy" currents in the disc.

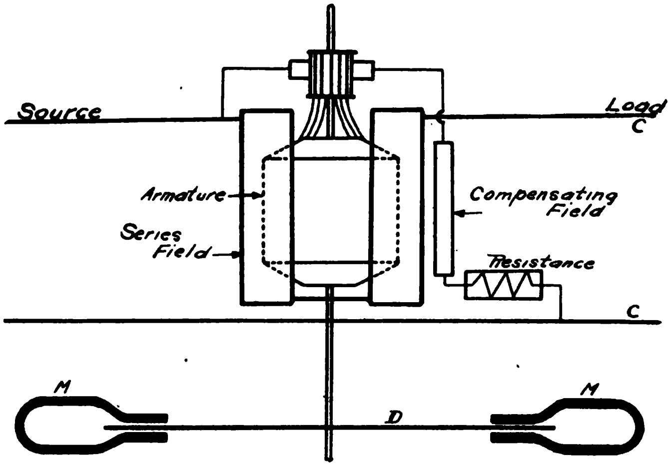


Fig. 44.

Principle of Operation.

The torque, or turning effort, of the motor is proportional to the product of the magnetic flux set up by the armature and that set up by the series field coils. The magnetic flux of the armature is proportional to the impressed e. m. f., and the magnetic flux of the series field coils is directly proportional to the current flowing through them. The product of the current and the voltage equals the power, therefore the turning effort of the armature is directly proportional to the power being expended in the circuit C. The power generated and expended in the disc itself depends directly upon the speed, since the eddy currents generated depend upon the rate at which the magnetic lines are cut, therefore the drag on the disc will be directly proportional to the speed. We therefore have an instrument in which the turning effort is proportional to the power passing through it, and in which the retardation, neglecting friction, is proportional to the speed. Since the speed will increase until the torque just balances the retardation, the revolving element will turn at a speed proportional to the power passing, which is the condition sought. The revolutions of the armature are transmitted through a suitable train of gears to the dials which register in units of electrical work, such as the watthour or the kilowatthour.

Comparison to a Shunt Motor.

There is one essential difference between the ordinary shunt motor and the motor of a commutating watthour meter, and that is the fact that the latter has no iron or steel in its magnetic circuit. If iron were employed in the meter, its torque would no longer be strictly proportional to the current flowing in the series field coils, due to the "saturation" effect of the iron, which would result in a greater reluctance (or magnetic resistance), with an increase in current. Therefore, on light loads, the torque would be correspondingly greater than at full load, thereby causing the meter to over-register on light loads, provided, of course, that it was adjusted to register correctly on full load, or vice versa.

It is a well known fact that the ordinary shunt motor will increase in speed if the field current is decreased, because the armature will then have to run faster in order to generate the "back" or counter e. m. f., under the conditions of a weaker field. On the other hand, a watthour meter will decrease in speed with a decrease in field current, or vice versa. These two facts are apparently contradictory and may be accounted for as follows: The speed of a shunt motor is proportional to the impressed e. m. f., and inversely to the field strength, and must be such that the back e. m. f. is equal (plus the RI drop) to the impressed e. m. f. Any weakening of the field will therefore cause an increase in speed, since the armature conductors have to cut the decreased field at a higher rate in order to generate the same back e. m. f. (For a full explanation of this theory, see any text book on direct current motors.) In the case of the meter, however, the counter e. m. f. is inappreciable, the impressed e. m. f. being practically all absorbed in the resistance of the armature, the auxiliary or "compensating field," and in the external resistance if any is used. So long as the voltage remains unchanged, the armature current will therefore remain unchanged, irrespective of the changes in the series field strength and the speed. The effect of a decrease in field strength is to decrease the torque, with a consequent decrease in speed until the retarding torque exerted by the permanent magnets on the disc is decreased to correspond to the turning effort of the armature. With an increase in field strength the reverse takes place, that is, the reaction between the armature current and the stronger field produces a stronger turning effort which increases the speed until the retarding effect of the permanent magnets increases to a corresponding degree. This condition of the operation of the meter holds true for an ordinary shunt motor until the counter e. m. f. is more than about 50 per cent of the line potential, below which point the speed of the shunt motor would increase with the field strength, and above which point the speed would decrease when the field strength was increased. Thus it will be seen that, in reality, there is no discrepancy between the motor of a meter and the ordinary shunt motor.

Efficiency.

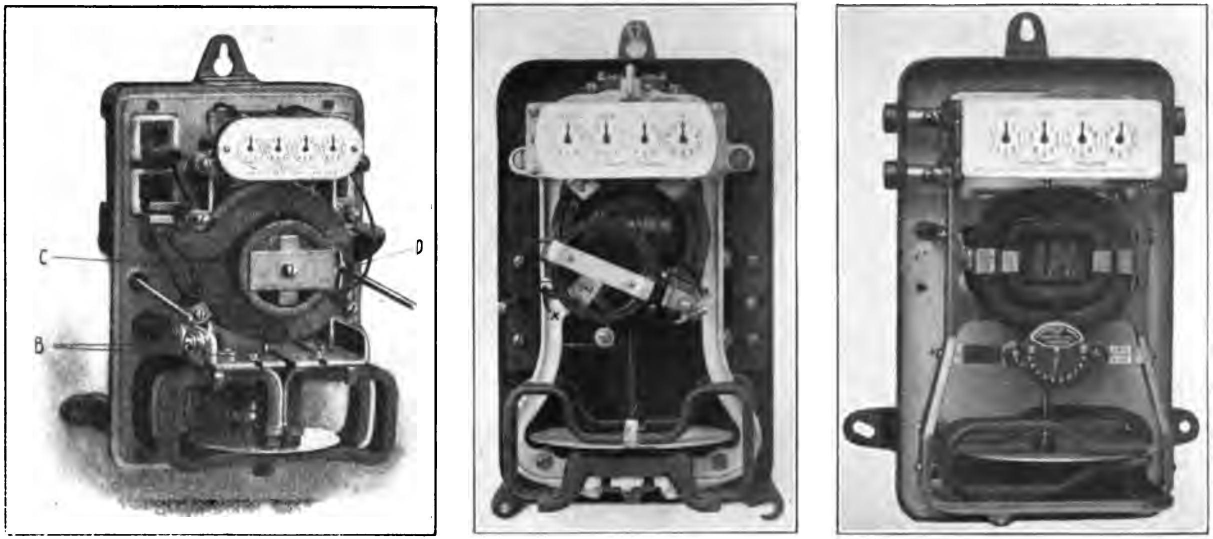
The efficiency of a meter is based upon the actual watts lost in the resistance of the series field coils and the potential circuit (which includes the armature, the compensating field and the external resistance), the losses due to friction, and the losses in the disc due to eddy currents set up by the retarding magnets.

During the early development of the watthour meter of the commutator type, the loss in the potential circuit alone, in a 100 voltmeter was about 10 watts, and in the 200 voltmeters was about 20 watts; such meters are now termed "low efficiency" meters; the present type or "high efficiency" meter has a loss in the potential circuit of about 4 or 5 watts in the 100 volt meter, and a loss in the series field coils not exceeding 1 per cent of the total capacity of the meter in the smaller capacity meters and much less than this in the large capacity meters. The reduction in losses has been accomplished by increasing the resistance in the potential circuit and by almost doubling the number of conductors on the armature; the number of armature conductors being increased to produce a greater torque.

General Construction.

Fig. 45 illustrates interior views of three representative types of commutating meters, in which (a) is the Westinghouse, (b) the General Electric, and (c) the Duncan, all of American manufacture.

The meter shown at (c) is designed for use on direct current circuits, although it may be said that the Duncan alternating current meter is very similar in construction, and its operation essentially the same



a. Westinghouse b. General Electric. c. Duncan.

Fig. 45—Types of Communicating Meters.

as the direct current meter. The use of the commutating type of meter on alternating current circuits will be dealt with later in this chapter.

The Compensating or Shunt Field.

The function of the compensating or shunt field is to compensate for friction, especially at light loads. When a meter is operating on a very small percentage of its rated load, the ratio of friction to torque is relatively great, therefore the lighter the load the greater will be the retarding effect of friction. In order to overcome this friction effect, the compensating field is connected in series with the armature so that its flux will work in conjunction with the main or series field. In the General Electric and Westinghouse meters, the strength of the compensating field is constant, and the "helping out" or compensating effect is altered by moving it closer to or further from the armature, so that more or less of its flux embraces the armature. In the Duncan meter, the amount of compensation is altered by means of the multi-point switch shown in the illustration. This switch is connected to various taps on the compensating winding and the variation is accomplished by cutting in or out a certain number of the coils, thereby altering the flux.

When the compensating field was first used, it was permanently fastened to the inside of the series field coils. This method was soon superseded by mounting it on an adjustable rack, so that it could be moved toward or away from the armature and then clamped in the correct position. The compensating field should be so designed that (in a new meter) it will allow a maximum boosting effect of about 10 per cent on light load, that is, it should have sufficient strength when adjusted for full compensation, to increase the speed of the meter by about 10 per cent when the meter is operating on 5 per cent of full load. This allows sufficient margin for adjustment as the friction increases. With compensating fields designed to give a greater boosting effect, the meter-man is apt to take advantage of the quick method of temporarily adjusting the meter and thereby compensate for excessive friction which by all means should be located and removed.

In the older types of meters (with especial reference to the Thompson recording type), on account of the low armature resistance, it was necessary to place an external resistance in series with the compensating field, such resistance being mounted in card form on the back of the meter case. This method has been simplified by having the entire resistance of the potential circuit (external to the armature) self-contained in the compensating field in all meters up to and including 250 volts. For the 500 and 600-volt types, it is still the practice to furnish a suitable external resistance for the potential circuit.

Brushes.

It is very important that the brushes be made of a material which will not vary in elasticity, and when once properly adjusted they should maintain their tension permanently. The control of the brush tension is effected either by gravity or by a spring. The actual contact surface of the brush should be made of silver since it has been found from practice that this material gives better service under operating conditions. Each brush (i. e., each positive and each negative) is usually divided into two parts, so as to give a more even distribution of pressure at the point of contact, and to make the brush self-aligning. Brush friction has been considerably reduced by using a cylindrical rather than a flat type.

The Commutator.

During recent developments in the manufacture of meters, the diameter of the commutator has been materially reduced, and at the present time some makes employ a diameter of less than one-tenth of an inch in meters of 110 and 220 volts capacity. This reduction in the size of the commutator has greatly reduced the friction of that particular member. It is general practice to make the commutator bars of pure silver, since this metal suffers least from oxidization, and therefore it presents a smoother surface and more constant contact resistance, two features which are desirable. The commutator is usually built up directly on the shaft, the bars being insulated from it and from each other and are held intact by a metal ferrule on each end of the commutator, the ferrules, of course, being properly insulated from the bars. In some cases the commutator bars are insulated from each other by fibre bars or other solid insulating material, and in other cases simply by an air space. Each of these methods, under certain conditions, are liable to give trouble. When a hard insulating material is used, it is apt to wear down slower than the commutator bars, causing the brushes to "ride," and thereby opening the armature circuit, which will either cause the meter to stop or else cause severe sparking. In case a soft material is used it is apt to gum the commutator and give rise to the same trouble as too hard an insulation. The trouble due to air-insulated bars, is that under extreme conditions, the air space may become filled with dust and small particles of metal, thereby causing adjacent bars to become short-circuited. A meter should be inspected often enough, though, so that under average commercial conditions the commutator with air-space insulation will give good service and will very probably be superior to the commutator with solid insulation.

The Armature.

There are two general types of armature construction at the present, the spherical and the rectangular. The tendency is to favor the spherical type, since this construction permits the field coils to be so designed as to allow a minimum leakage of magnetic flux, thus securing the highest possible torque for a given watt loss in the fields and armature windings, and thus approximating more nearly the condition of an ideal meter.

In both the spherical and the rectangular wound armatures, the winding is of the well-known "Siemens drum type." The rectangular winding is usually supported by two spiders made of small strips of hard wood and properly secured in position on the shaft. The supporting medium in the spherical wound armature consists of two hemispherical pieces of fibre which are mounted directly on the shaft, the windings themselves being held in position by grooves which are stamped in the fibre shells. This construction is good mechanically and insures a very light weight of moving element. The full load speed of the commutating type of meter is usually about 40 r. p. m., which further permits of very light armature construction.

Generally speaking the armatures of meters for use on 110-volt circuits or thereabouts usually have 8 armature coils of about 1000 turns each, of number .003 copper wire, and those of 200 volts and above have 16 coils of 500 turns each, of the same size wire. This method of subdividing the coils on the higher voltages is followed so that there will not be such a great difference of potential between adjacent coils nor between the commutator bars. There is one commutator segment per coil, for instance, in a 100-volt meter there will be 8 commutator segments, and in a 200-volt meter there will be 16 segments.

The total armature resistance in meters from 100 volts to 600 volts inclusive, of the ordinary house type, is usually between 1000 and 1200 ohms, the proper amount of resistance being placed in series to limit the current on the various voltages. The armature current is practically the same for all voltages from 100 to 600 inclusive, the total resistance of the potential circuit being subdivided approximately as shown in the table below:

TYPE OF METER	Shunt Field Resistance	Armature Resistance	Total Resistance	Total watt Loss Potential Circuit	Armature Current Amperes
5 amp., 2 wire, 110 v.....	1,300	1,200	2,500	5	0.0447
5 amp., 2 wire, 220 v.....	3,800	1,200	5,000	10	0.0447
5 amp., 2 wire, 550 v.....	10,900	1,200	12,100	25	0.0454

It is thus seen that the armature current is practically constant.

While on the subject of armatures, it should be borne in mind that the temperature coefficient of the armature and the disc should be the same, so that any decrease in torque of the armature, due to a rise in temperature, will be correspondingly offset by a rise in resistance of the disc, which in turn would decrease the effect of the retarding magnets.

Fig. 46.—Parts of a Typical D.C. Watthour Meter.

Other features of construction have been dealt with in Chapter I.

The Use of the Commutating Meter on Alternating Current Circuits.

As previously explained, the commutating type meter is a simple shunt motor, and this being the case, the question may arise, "Why is it that such a meter can be operated with accuracy on alternating current circuits?" It should first be remembered that, owing to the iron in the magnetic circuit of an ordinary shunt motor, there would be a great difference in phase relation between the current in the armature and the current in the fields if such a machine was supplied with alternating current, this being due to the much greater inductance of the field winding. The current in the fields would lag almost 90 degrees behind the current in the armature, therefore the torque produced would not be sufficient to cause rotation. The meter, being as it is, devoid of iron in its magnetic circuit, will not suffer from such a phase difference when supplied with alternating current.

The commutating type of meter can be made to operate with accuracy on alternating current circuits by making an adjustment which is termed "lagging." If this type of meter is used on alternating current, precisely the same as on direct current—that is, without any adjustments—the current in the armature will lag a few degrees behind the impressed voltage, while the current in the field coils, for a load of unity power factor, will be in phase with the impressed voltage; the lag in the armature current being caused by the inductance of the armature and the compensating field. This, however, does not introduce a serious error at unity power factor. In order that the meter may register correctly on power factors other than unity, it is necessary that the current in the armature be in phase with the current in the series field when the meter is operating on a load of unity power factor. It is therefore necessary that an adjustment be made that will bring the two currents in phase, thereby correcting the small phase difference above referred to. Such an adjustment is accomplished by shunting a part of the current in the series fields through a non-inductive resistance. By properly adjusting this resistance, the current in the series fields can be made to "lag" until it is in phase with the armature current.

The principle or theory of this method of adjustment may be explained as follows: The series coils have both resistance and inductance, and when shunted by a non-inductive resistance, the line current is divided into two components, one of which flows in the non-inductive resistance and the other in the field coils themselves. (The current in the non-inductive resistance is a small percentage of that flowing in the field coils.) The relative values of these two components of the line current are inversely proportional to the impedances of the two paths, and the phase angle between them will depend upon the ratio of the resistance to the reactance of the series coils. This is diagramatically shown at (a) in Fig. 47, where OV represents the impedance drop around the series coils and the non-inductive resistance together; i being the current in the resitance and i′ the current in the series field coils. The voltage drop, Ri, in the non-inductive resistance, will be =OV, and i will be in phase with OV. The drop in the series coils, however, consist of two components, a resistance drop, R′, i′, which is in phase with i′, and a reactive drop xi′ at 90 degrees from i′, the phase angle between i and i′ being represented in the figure by ϕ.

The main line current is made up of these two components as shown at (b) in Fig. 47, and it can be seen from this that the angle ρ, which is the lag of the current i′ in the series coils behind the line current I, can be adjusted by merely changing the value of the current i in the non-inductive resistance.

After having properly lagged the meter on say 50% power factor, it is necessary to recalibrate it, since the torque exerted by the series coils will be less than before the adjustment was made, as the total line current is no longer flowing in the series coils. This recalibration is made by adjusting the retarding magnets, after which the meter will be accurate for all power factors above 50%. An unlagged commutator meter will have a tendency to run fast on inductive loads. In any event, where it is necessary to lag commutating meters it is advisable to take the subject up with the manufacturer of the meter in question, and obtain their recommendations. In all cases involving a great number of meters, it is advisable to change the entire installation over to the induction type on account of its greater simplicity and superior operation on alternating currents.

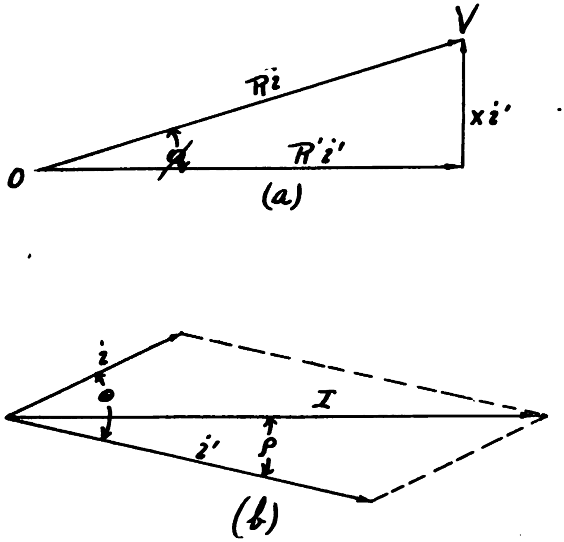


Fig. 47.

Three-Wire Meters.

In the heart of cities, and in buildings where a large amount of current is used, the three-wire system of distribution is almost always to be recommended on account of the great saving in the amount of copper in the distributing wires, the most common system being the 220/110-volt system, the current being furnished (in case of direct current) by either a three-wire generator, a two-wire generator with a balancer set, or by two generators operating on a three-wire connection. The question often arises as to what extent should the distributing company insist upon having the system balanced. In New York City the requirements are very rigid. For instance, all lighting circuits taking more than five amperes must be equally divided between the two sides of the system, and all motors over 5 h.p. must be connected across the outside wires. On the other hand, some companies pay no attention whatever to the "balance," and depend upon the average conditions to balance the load at the station bus-bars. At the point of distribution, however, the conditions may not be so favorable as at the station, thereby resulting in poor service on

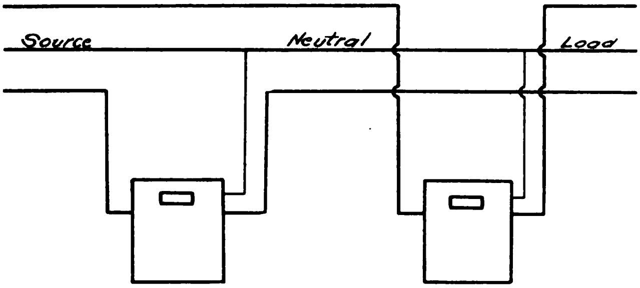


Fig. 48.

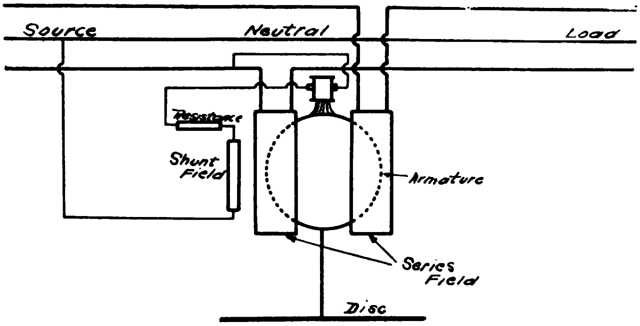


Fig. 49.

one side or the other of the system. It is therefore recommended that some effort be made to keep the load fairly well divided between each of the two outside wires and the neutral.

To measure the power flowing in a three-wire system, it is necessary to use two meters connected as shown in Fig. 48, or to use one three-wire meter whose internal connections are shown diagramatically in Fig. 49. The only way in which the three-wire meter differs from the ordinary two-wire meter is that in the former the series field coils are divided into two equal sections, which are connected in the opposite sides of the system as shown above.

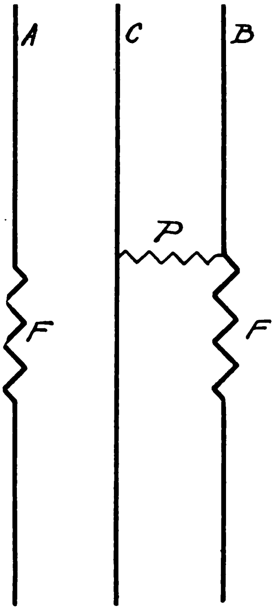


Fig. 50.

There are devices on the market for automatically connecting the potential circuit to the opposite side of the line without reversing the direction of rotation of the meter in case one side of the three supply wires should be disconnected.

The armature circuit is usually connected between the neutral and one of the outside wires in the three-wire meters, because such practice permits cheaper construction, due to the lower voltage impressed. (In Fig. 50, P represents the armature circuit and FF the series field coils.) In either case—that is, with the armature circuit across the outside wires or across one outside wire and the neutral—the three-wire meter is subject to error on unbalanced loads; if connected to neutral it may register either slow or fast, depending upon whether the voltage between C and B (Fig. 50) is less than or greater than one-half the voltage between A and B. If the potential circuit is tapped from A and B, the meter will usually register high on unbalanced voltage, as the lower voltage will usually be on the heavier loaded side. It is very seldom that the unbalancing of the load on a three-wire system is such that it will cause any great degree of inaccuracy, but if extreme accuracy is a question of prime importance it is recommended that two two-wire meters be used rather than one three-wire meter on a poorly balanced system.

High Capacity Meters for Switchboard Service.

In order that the distributing company may have an exact comparison between the power actually delivered from the station bus-bars and the delivered power from which a revenue is realized, it is of the utmost importance that switchboard meters be carefully selected as to their accuracy and their capacity. The question of "over-metering" as brought out in Chapter I applies with even more force in the case of switchboard meters—the detection of unwarrantable losses depends primarily upon the switchboard meters. It will be found in almost every case that it is more desirable, for several reasons, to use individual meters on the various generators or feeders than to use "total-output" meters. In the first place, if a single meter is used, its capacity will have to be greatly in excess of the average load, in order that it may take care of the "peak" load, consequently the large meter will be running far below its maximum efficiency the greater part of the time. Secondly, if it is desired at any time to increase the capacity of the station, the individual method of metering will be found to be much more flexible than will the total output meter method. In the third place, it is much more convenient to test the smaller, individual meters, on account of their lighter connections and the ease with which testing instruments may be inserted in the circuits. All switchboard meters should be so installed that future testing may be done with the least possible trouble and inconvenience.

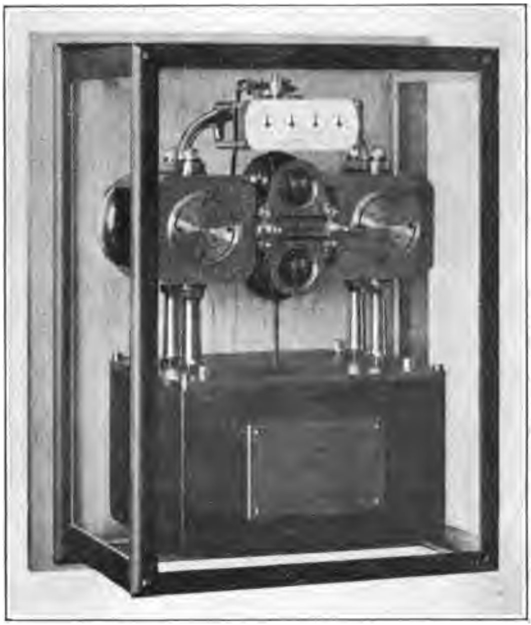


Fig. 51.

High capacity meters for direct current switchboard service are, in almost every case, subjected to the influence of powerful stray fields produced by the bus-bars which are usually in close proximity to the meters; short-circuits and overloads also give rise to disturbing influences. In order that switchboard meters be free from such disturbances, special construction is necessary. Fig. 51 is an example of a high capacity meter, the one illustrated being for 3000 amperes. The two armatures are "astatically" arranged—that is, they are so connected that should the influence of a stray field tend to weaken the torque of one armature, it will correspondingly strengthen the other, and vice versa. It will also be noticed that the retarding magnets are completely shielded by a rectangular metal box which is built up of soft steel punchings, which will effectually divert any stray lines of magnetic force which would otherwise affect the accuracy of the meter. Very often it is found necessary to place such a shield on a meter after it has been installed, after which it will also be necessary to recalibrate the meter, because the close proximity of the shield to the retarding magnets will cause a leakage of flux, thereby decreasing the retardation of the magnets. This effect is usually slight, but it is always better to recalibrate the meter.

The series field coils of the meter shown in Fig. 51 are of the "bus-bar" type, the magnetic field being produced by a straight copper bar which carries the current from one of the large studs past the armature to the other stud, the effect being that of a single turn. The standard sizes of this type range from 2000 to 10,000 amperes at potentials from 100 to 600 volts inclusive.

Switchboard watthour meters ranging in current from 50 to 1500 amperes have the same astatic features as above noted, but instead of having the "bus-bar" field coil, they have several turns of heavy copper. Their damping system should also be encased in a protecting steel box when the meter is in the neighborhood of conductors carrying large currents.

Another difference between the switchboard type of meter and the ordinary house type is that in the former, all resistance in series with the armature or the compensating field is usually external to the meter case, thus minimizing the heating effect from this source.

In selecting a switchboard meter, the following points should be borne in mind: The meter should have a high torque, continued high accuracy, light weight of moving element, and should have its armatures and retarding magnets astatically arranged.

A recent development has been made in the design of switchboard meters which further protects it against the disturbing influence of stray fields. This is accomplished by making the "motor" a four-pole rather than a two-pole motor. By this arrangement it is possible to place two adjacent (positive and negative) poles much closer together than in the case of the two-pole design. It will therefore be readily seen that a stray field coming from any direction will tend to more equally strengthen one pole and correspondingly weaken the other, than in the case of a two-pole meter.

This type of meter can of course be used for ordinary service as well as for switchboard service, provided the conditions warrant the expense of the four-pole meter.

Connections of Commutating Type Meters.

The connections of the commutating type of watthour meters when used on direct current circuits are so simple that it is not deemed necessary to give but a few characteristic connections which are shown in the following figures:

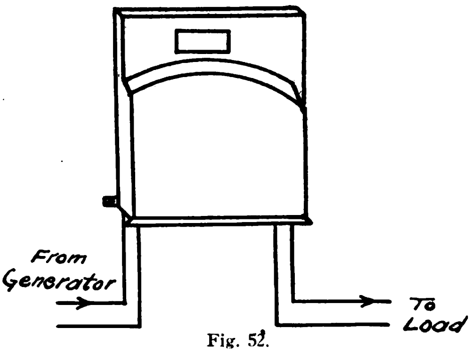


Fig. 52.

Fig. 52 shows the connections of a small capacity (3 to 50 amps.) two-wire "T. R. W." meter, of which there are still quite a number in service. Fig. 53 is the same type meter for two-wire service in capacities of from 75 to 1200 amperes. Fig 54 is the "T. R. W." three-wire, 3½ to 150 ampere meter.

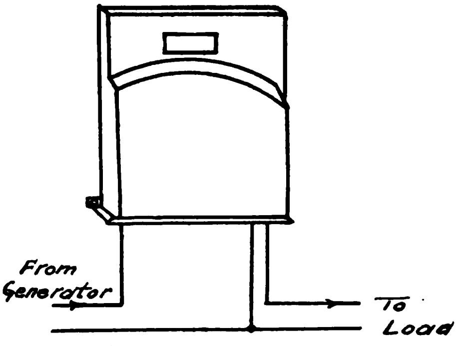


Fig. 53.

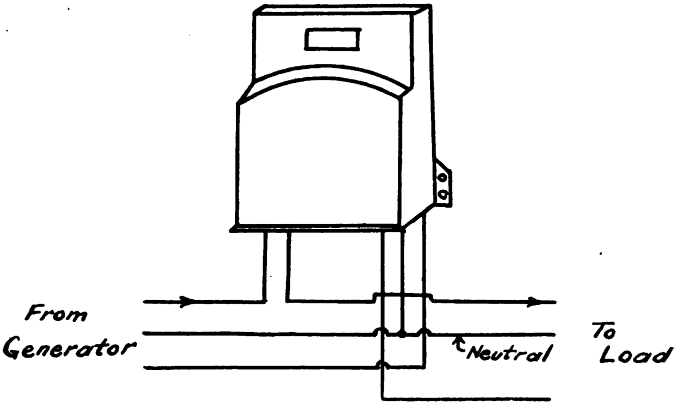


Fig. 54.

Fig. 55 shows the connections of the General Electric type "C" watthour meter for
5 to 25 amperes, 500/600 volts, 2 wire (C-6 and C-7)
50 amperes, 100/250 volts, 2 wire (C-6).

Fig 56 is the connection of a General Electric type "C":
75 to 600 amperes, 100/250 volts, 2 wire (C-6 and C-7).
50 to 600 amperes, 250/600 volts, 2 wire (C-7).

It will be noticed that in Fig. 56 that only one line wire is carried through the meter on account of the large size of the conductors.

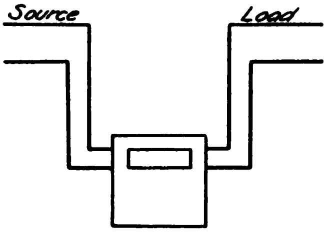


Fig. 55.

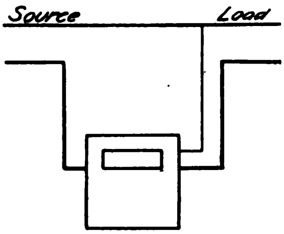


Fig. 56.

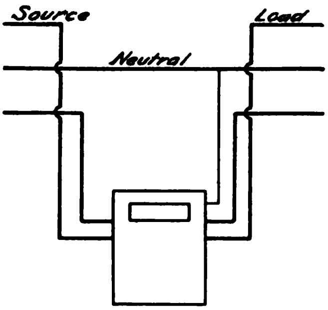


Fig. 57.

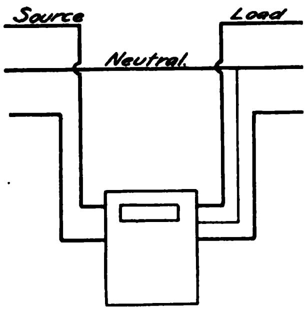


Fig. 58.

Fig. 57 shows connections of a General Electric type "C":

5 to 50 amperes, 200/240 volts, 3-wire meter.

Fig. 58 shows connections of a General Electric type "C":

75 to 300 amperes, 200/240 volts, 3-wire meter.

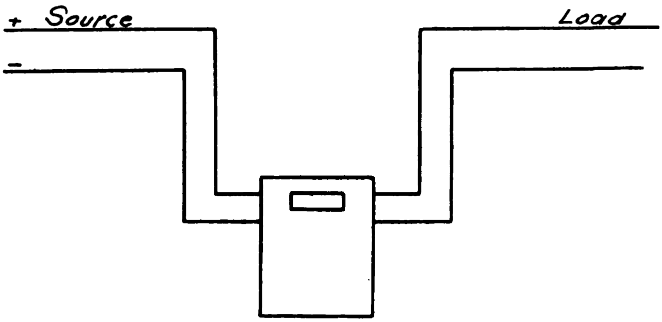


Fig. 59.

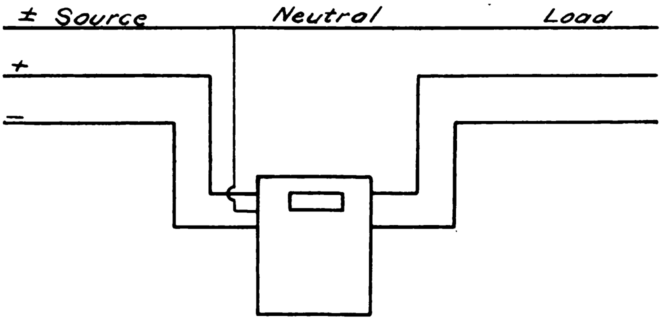


Fig. 60.

Figs. 59 and 60 show connections of the Westinghouse two-wire and three-wire direct-current meters, respectively.

CHAPTER V.

THE MERCURY FLOTATION WATTHOUR METER.

The Sangamo Electric Company of Springfield, Ill., manufactures a type of watthour meter which is

Fig. 61a. Sangamo Meter.

radically different in operation from the induction and commutating types of meters previously explained. The Sangamo meter is of the mercury flotation type and its principle of operation is based on an old discovery made by the scientist, Faraday, when he found that a pivoted metallic disc carrying electric current would tend to rotate when under the influence of a magnetic field.

The fundamental discovery of Faraday is very ingeniously utilized in the Sangamo meter. A copper disc is enclosed in a suitable chamber made of moulded insulating material which is divided horizontally into two sections, the chamber being partially filled with mercury. In the lower part of the mercury chamber there are imbedded two copper terminals which serve to conduct the current to the copper disc through the intervening mercury. The mercury serves the double purpose of conducting the current to the disc and of buoying up the disc so as to make the weight on the lower bearing very slight. The copper terminals are

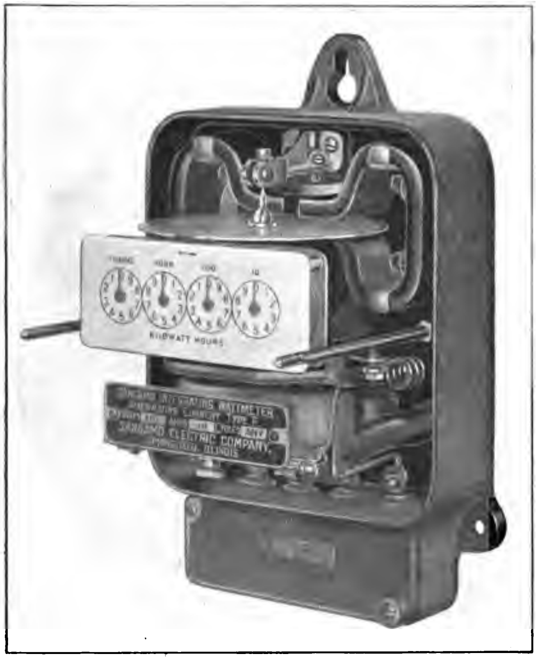


Fig. 61b. Sangamo Meter, Cover Removed.

arranged diametrically opposite as will be seen from Fig. 62. The exciting magnet which produces the flux which acts upon the disc is imbedded in one section of the moulded "mercury chamber."

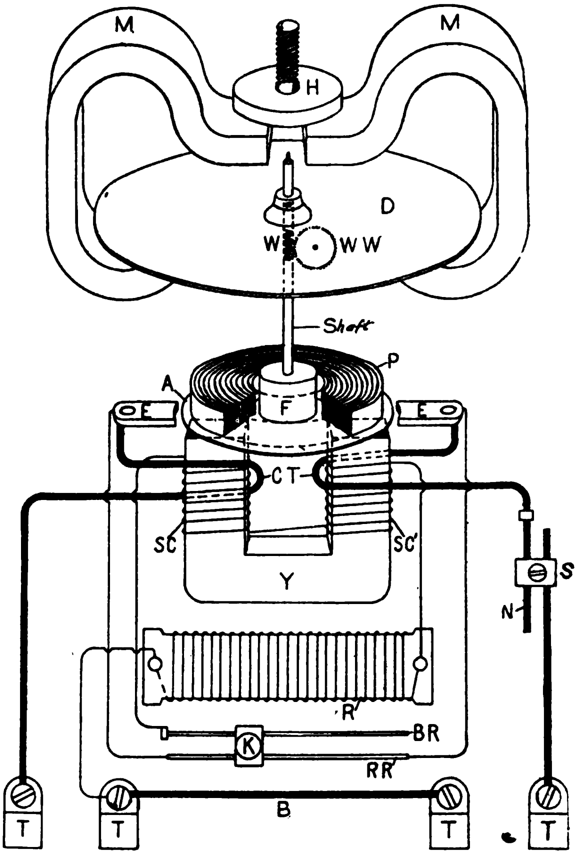


Fig. 62.

In the case of the direct current Sangamo meter the main line current, or a proportional part thereof, passes through the copper disc, the magnet being excited from the potential of the circuit upon which the meter is being used. In the case of the alternating current meter, the method of excitation is opposite from the direct current meter, that is, the magnet is excited by the line current, and the disc carries a current which is proportional to the potential of the circuit.

The reaction of the current in the disc with the magnetic lines of force from the magnet will cause the disc to rotate at a speed which will be proportional to the product of the current and the impressed e.m.f., in other words, it will rotate at a speed which will be proportional to the power being expended in the circuit to which it is connected. In alternating current meters operating on a circuit whose power factor is other than unity, the speed of rotation will then be proportional to the current, the e.m.f., and the power factor.

Under ordinary conditions a variation in temperature between 10° F., below zero, and 110° F., will not materially affect the operation of the mercury meter, but temperatures above or below these maximum and minimum values are liable to affect the accuracy. There is sufficient space in the mercury chamber and such a (comparatively) small percentage variation in the volume of the mercury with changes in temperature that the expansion of the mercury will not cause it to leak out, as is sometimes supposed.

The direct current Sangamo meter cannot be used on alternating current circuits because of the high self-inductance of the potential winding. Therefore, if alternating current be applied to a direct current meter very little current would pass through the potential coil, and even that would lag by so many degrees that it would produce a very small torque.

Fig. 62 shows diagramatically the Sangamo direct current meter. The damping system in this type of meter is essentially the same as previously explained in connection with induction and commutating types of meters. In the above figure the damping magnets are shown at M, and the damping disc at D. The copper terminals which lead the current into the mercury and thence to the disc, A, are shown at EE. The external resistance, R, is in series with the potential winding, SC. The light load adjustment is made by moving the slider, K, to the right or left, thereby causing part of the shunt current passing through the potential winding to flow through the armature. This current reacting with the magnetic field from the potential winding produces a no-load torque which is sufficient to compensate for friction.

The torque of the Sangamo meter is very low, the torque of a 5 ampere direct current meter being only about 20 gram-millimeters. It may be said, however, that in the case of the mercury flotation meter the pressure on the jewel bearing is relatively small, and it is therefore not necessary to have as high a torque as in other types. The reason for this low torque in the Sangamo meter is due to the fact that the armature is equivalent to only one turn, and as it is not practicable to carry more than 8 or 10 amperes through the armature, the effective armature turns will necessarily be low. Current shunts are used in all direct current Sangamo meters having a capacity of more than 10 amperes, the shunt being external in large capacity meters and internal in the smaller sizes. The sliding connector, S, shown in Fig. 62 is used for adjusting the armature current with respect to the shunts.

It is not feasible to build the mercury meter for three-wire direct current service, since it would necessitate the construction of two separately insulated mercury chambers and armatures, which would of course be too bulky, complicated and expensive to be warrantable. Two mercury meters have to be used where it is desired to measure the power in a three-wire direct current circuit, with this type of instrument.

The alternating current meter of this type is shown diagramatically in Fig. 63. As will be noted, the armature circuit is in shunt with the source of supply in this case, as was above mentioned, rather than in series as is the case with the direct current type The small potential transformer, N, has its primary, PT, connected across the line and induces through its secondary, MS, a current of high amperage and very low e.m.f. This current flows directly through the armature as is shown. The actual value of this secondary current is between 12 and 20 amperes

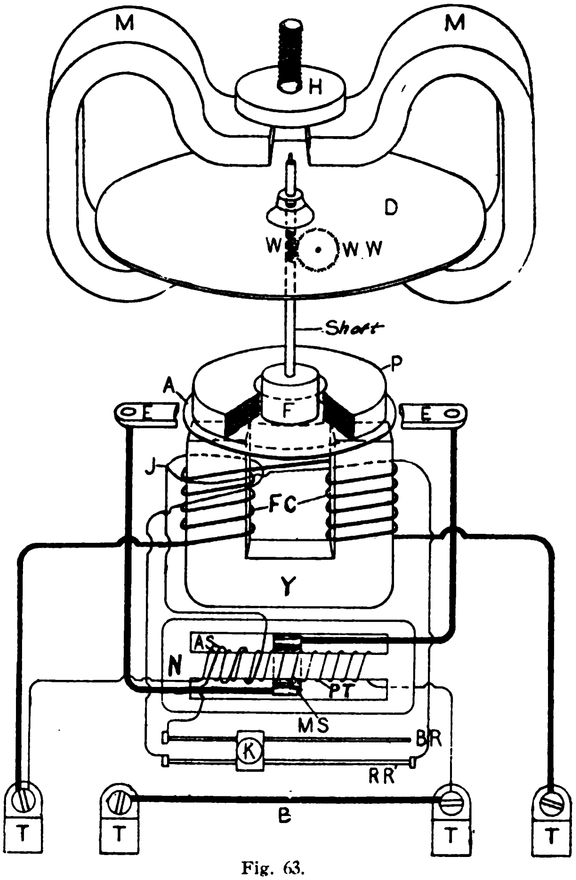


Fig. 63.

at an e.m.f. of approximately 0.05 volt. The transformer also has an auxiliary secondary winding, AS, the terminals of which are connected through the variable resistance, RR, to the light load adjusting coil, J, which is wound on the same core with the series field coils, FC. By moving the slider, K, along the resistance the compensating effect of the light load adjustment may be varied to allow for friction.

The full load adjustment in the Sangamo meter is quite different from the usual practice, in that the damping effect of the retarding magnets is varied by "shunting" more or less of the magnetic lines through a soft iron disc, H (Figs. 62 and 63), which is placed directly above the magnet system, rather than by moving the magnets themselves. This soft iron disc is movable in a vertical direction as shown; by bringing it in close proximity of the magnets, it weakens their effect, thereby causing the meter to run faster.

The Ampere-Hour Meter.

The Sangamo ampere-hour meter, is now being used quite frequently in connection with the charging and discharging of storage batteries. Storage batteries are rated on their ampere-hour capacity, and it will therefore be seen that an instrument which will indicate the amount of current that has been stored in, or the amount of current remaining in a battery is a valuable accessory to the electric automobile garage, or in fact to any one having the care of a storage battery.

The construction of the Sangamo ampere-hour meter is essentially the same as that of the watthour meter, except that the exciting electro-magnet is replaced with a powerful permanent magnet. The turning effort of the armature will therefore be independent of the potential of the circuit on which the meter is used, being directly proportional to the current passing through it. This type of meter is usually furnished with a single pointer, which will show at a glance the condition of the battery with respect to the charge or discharge. The dial may be furnished with a movable contact, which by means of a relay can be made to open the main circuit through a "shunt-trip" type of circuit-breaker; this movable contact can be set so as to open the circuit at any predetermined value.

Connections.

A few representative connections of the Sangamo meter are shown in the following figures:

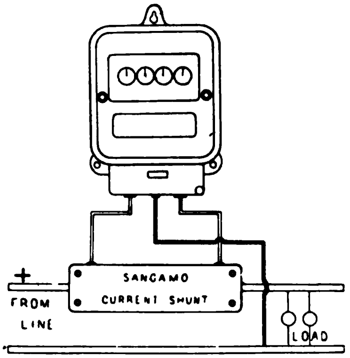


Fig. 64.

Two-Wire D. C. Meters—110 to 250 volts; 100 to 400 amperes, inclusive, box type "Current Shunt." New "Pocket Type" Shunt used in capacities 100 to 200 amperes, inclusive, except for street railway service.

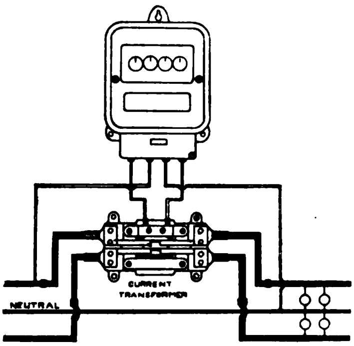


Fig. 67.

Three-Wire Alternating Meters—110-220 volts single-phase; capacities 200 amperes per side and over. With Current Transformer having two primary windings.

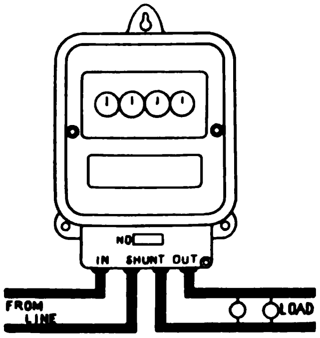


Fig. 65.

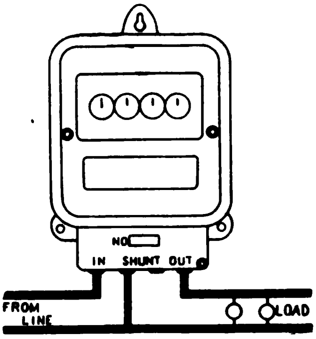


Fig. 66.

Two-Wire Meters—110 and 220 volts, for A. C. Meters 5 to 100 amperes; D. C. meters 5 to 80 amperes, inclusive. Meters may be connected according to Fig. 65 or Fig. 66, but the former is preferable, as this method prevents tampering with the meter connections.

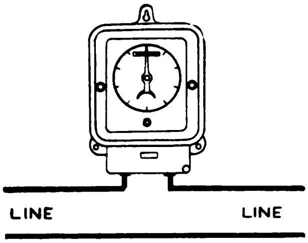


Fig. 68.

Service type, ampere-hour meter, 10 to 100 amperes internally shunted.

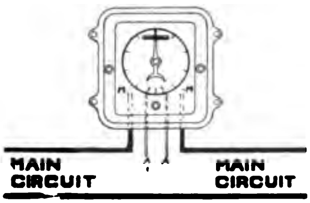


Fig. 69.

"Auto" type, ampere-hour meter, with contact device and auxiliary circuit for tripping a circuit-breaker. Capacity 10 to 100 amperes.

CHAPTER VI.

MISCELLANEOUS.

The Pre-Payment Watthour Meter.

The prepayment device as applied to the gas meter has demonstrated its usefulness after a number of years of service, it being especially valuable in cities where many of the consumers are transient residents, and also where those served find it a burden to make the usual monthly payments, preferring to pay as occasion demands. The slow introduction of prepayment electric meters has been partly due to the limited demand, because usually the class of people that have been using electricity for light, power, heating and cooking have not been of the kind that would

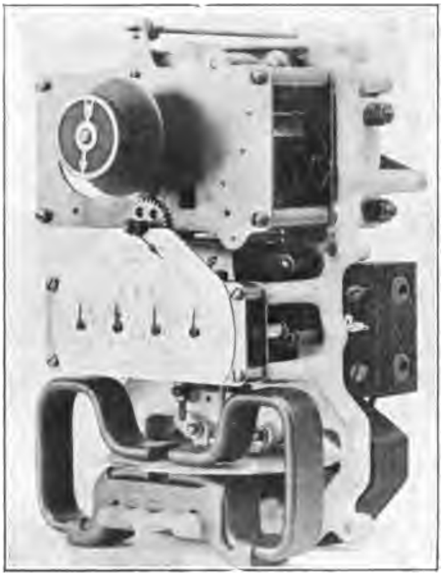


Fig. 73.

desire or that would necessitate the installation of prepayment meters. Now electricity occupies such a broad field that it may be said to be used by all classes of people, therefore the distributing company is often confronted with the problem of "slow pay" customers. Especially is this true with small commercial establishments, such as the poorer classes of restaurants, saloons, tailor shops, etc. The prepayment meter when installed in such places will oftentimes obviate difficulties which may otherwise arise.

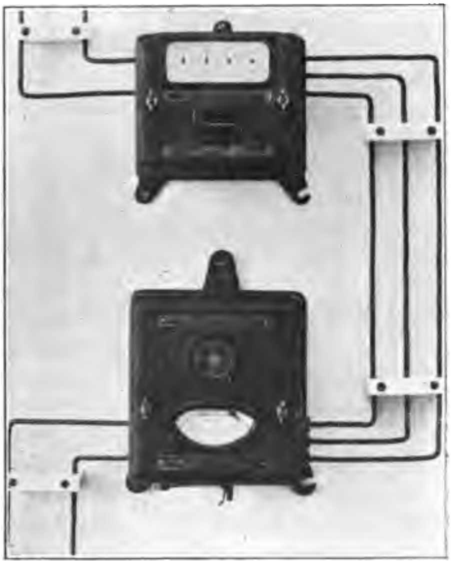


Fig. 74.

The prepayment device can be furnished either as an integral part of the watthour meter, or as a separate device. The construction and operation in either case is essentially the same, except that in the former case the connection to the meter is mechanical and in the latter case it is electrical. Fig. 73 illustrates the prepayment device attached directly to the watthour meter, in which case a pinion in the registering mechanism of the meter meshes directly with the debiting mechanism of the device. In case the prepayment device is used separately from the watthour meter, the debiting mechanism is controlled by an electromagnet which is connected directly in the line, contact being made through suitable gears and commutating device in the meter register.

Fig. 74 shows the prepayment device when used as a separate part of a watthour meter.

Construction and Operation.

The small knob shown protruding from the front of the case is provided with a slot for the reception of coins of the proper denomination. After the coin is placed in the slot the knob is given a half turn to the right, the coin engaging the shaft of the crediting mechanism and the main circuit being simultaneously closed. The coin is carried around with the turn of the knob and released into a chute which conveys it to a coin chamber in the base of the meter. The first coin placed in the slot will cause the indicating hand to move to the figure "1" on the crediting dial, the second coin will cause the hand to move to the figure "2," and so on, provision usually being made to accommodate twelve quarter dollar coins at once. Thus $3.00 worth of current may be paid for in advance, and as each quarter's worth is used, the debiting mechanism will cause the indicating hand to recede to the next figure. The dial, therefore, only indicates the number of coins to the credit of the consumer and does not take into account the coins for which energy has already been delivered. The total number of coins placed in the device can always be readily translated from the watthour register by multiplying the reading in kilowatt hours by the rate per kilowatt and dividing the result by the denomination of the coin. When all the energy which has been paid for has been delivered, the crediting hand moves back to the zero position and opens an internal switch, which cannot be again closed until another coin is deposited. The switch contacts are made of laminated copper strips which insure good electrical contact.

The force which actuates the debiting device consists of a large spiral spring. This spring exerts practically a constant force, since it is so designed that it is always operating under a low percentage of its maximum tension. The gearing mechanism of the spring is "differential" in operation, so that the escapement is independent of the knob. This permits the consumer to place more coins in the device before all energy paid for has been delivered, without in any way disturbing the crediting and debiting mechanism. The prepayment device is usually made for rates ranging from 5 to 20 cents per kilowatt-hour in steps of one-half cent. Each prepayment device is marked with the rate per kilowatt-hour with which it should be used; if, however, it is desired to change this rate of charge it is only necessary to change the gear ratio of the "rate device," the construction being such that this is easily accomplished. The coin receptacle is in the back of the meter and so located and protected that the meter cover may be removed (for testing and inspection), without giving access to the coin receptacle. It consists of a drawer which can be slipped in or out from the bottom of the meter case, so that it is not necessary for the collector to remove the meter cover when taking out the coin. Lugs (as will be seen from the illustration) are furnished so that the coin receptacle can be locked by means of a suitable padlock.

The manufacturing companies have perfected the prepayment device to such a degree that it is as trustworthy as the gas meter device, and they have designed it so that "beating" is practically impossible. When a coin is once placed in the slot, the knob cannot be turned back until a half turn has been completed and the coin has dropped into the chute. A coin of smaller dimensions than that for which the slot is designed will not allow the knob to be turned. The credit knob is provided internally with a sharp edge which will shear off any thread or fine wire that may have been attached to the coin with fraudulent intentions.

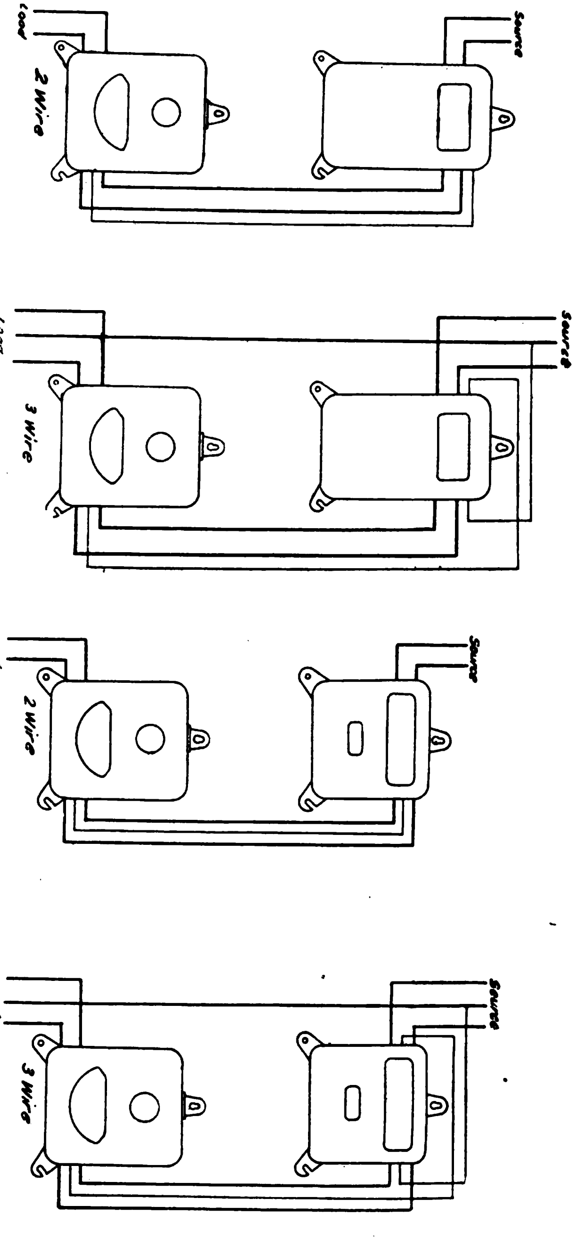
The prepayment attachment for the electric meter has the advantage over the gas device in that it may be placed at any point remote from the meter which it controls. The electric meter may be in the attic, the basement or on the back porch, and the prepayment device in the kitchen or other convenient place.

The diagrams, Fig. 75, show the connections of the prepayment device above described when used in connection with alternating and direct current watthour meters as manufactured by the General Electric Company.

The Wright Demand Indicator.

The need of an instrument which will indicate the maximum demand made upon the current supply of a distributing company has lead to the development of the device shown in Fig. 76, which is known as the "Wright Demand Indicator." As will be noted from Chapter VIII, relative to rates, the cost of serving a customer whose average load for 24 hours, compared with his maximum, is high, will be lower than the cost of serving a customer the ratio of whose average to maximum load is low. In other words, the customer with a good "load factor" is more profitable to the distributing company. For example, suppose that a given customer has a connected load of lamps amounting to 10 kw. which are being supplied with current for only two hours in the evening, and suppose that another customer has a connected load of motors amounting to 2 kw. that takes current for ten hours. In either case, the kilowatt-hours per day are the same, but the lighting load comes when the demand upon the station is at the highest point; whereas, the motor customer is being served when the generating machinery would otherwise be running partially loaded. It is therefore evident that the customer whose demand is practically constant, such as the motor customer, is the most profitable, and is entitled to a better rate.

The Wright Demand Indicator can be, and is used to great advantage in determining the maximum


Load
Source
2 Wire
Load
Source
3 Wire
Load
Source
2 Wire
Load
Source
3 Wire

D. C.

A. C.

Fig. 75.

load on transformers. Its systematic use in determining the actual maximnm loads on the transformers of a distributing system will insure the transformers against excessive overloads. As is the case with meters, it is not infrequent that transformers of too large a capacity are used for supplying a given connected load; the maximum demand indicator is valuable in determining the proper capacity of distributing transformers. The indicator may be mounted on the pole and connected in the circuit by replacing one of the primary fuse-plugs with the plug having loose connections which are attached to the terminals of the indicator. When the indicator is used in this way it should be mounted on a suitable board, which will facilitate handling and also prevent breakage. The indicator can also be applied to motors driving machine tools, etc., to ascertain whether or not they are being operated in excess of their guarantees.

Around the upper, or left hand bulb, shown in Fig. 76, and in close thermal contact with it, is a band of resistance wire through which passes the main line current or a proportionate part thereof; shunts being provided with high capacity direct current indicators. and current transformers with the larger sizes for use on alternating current circuits. The current in passing through the resistance band heats the air in the glass bulb, which in turn causes the air to expand, thereby forcing the liquid up into the right-hand tube, the liquid then falling into the central or index tube, which is set in front of the scale. The heat generated in the resistance band is proportional to the square of the current passing through it (watts dissipated in resistance = resistançe × the square of the current flowing).

The difference in temperature of the air in the two bulbs causes the liquid to flow as it does, and since any external temperature affects the air in the two bulbs similarly, no error will result due to changes in temperature of the surrounding air.

The tube is reset by simply tilting it and allowing the liquid to flow out of the index tube back in to the

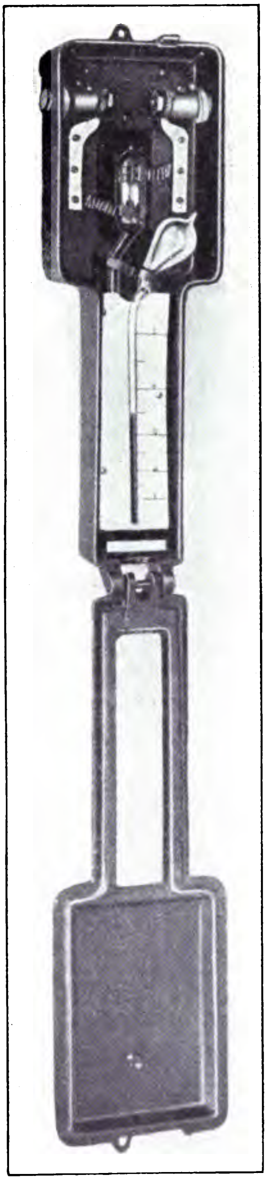


Fig. 76.

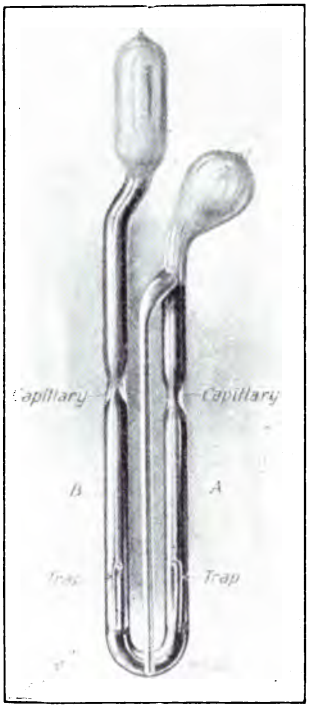


Fig. 77.

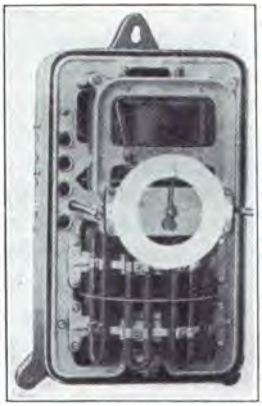


Fig. 78.

U tube. In resetting the indicator, air bubbles from one arm of the U may be carried over into the other arm, thereby unequalizing the pressure and causing the calibration to be disturbed. To prevent this trouble, the little traps shown in the illustration are located in the bottom of the U, and when the tube is inverted (or partially so), they remain covered with the liquid, due to the action of the capillaries in the channels of the U tube, and thereby prevent the passage of air from one side of the U to the other side.

The Induction Type Watt Demand Indicator.

The Wright Demand Indicator which has just been described deals with the current only, and does not take into consideration the power factor of the circuit on which it is used nor fluctuations in line voltage. It is often necessary to know the maximum watt demand, especially in the case of motor installations. To fulfill the requirement of such a device the General Electric Company has designed the instrument shown in Fig. 78, which is known as the "Polyphase Maximum Watt Demand Indicator." This instrument will indicate and register the maximum watt demand on single, two or three phase systems having a balanced or an unbalanced load, and irrespective of the power factor and voltage fluctuations.

This type of indicator is simply a modification of the polyphase watthour meter, the ordinary retarding magnets being replaced by a greater number of very powerful permanent magnets arranged as shown, and with both electrical elements acting on the upper disc. The register as ordinarily furnished on watthour meters is replaced by a circular scale having two concentric pointers, one of which is connected to the disc shaft through a suitable train of gears; the other pointer being driven by the first pointer. As the load on the indicator causes the first pointer to deflect, the second pointer is carried to the maximum position reached by the first pointer, in which position it is held by a ratchet.

The upper, or "motor" disc is opposed and controlled by phosphor-bronze springs which confine the rotation of the disc to a definite number of revolutions. The torque acting on the disc is proportional to the power passing through the indicator, therefore by using a control spring of many convolutions, the graduation of the scale can be made uniformly.

A curve showing the relation of the percentage of deflection to the time during which it takes the pointer to reach such deflection is shown in Fig. 79. It will be noticed that the curve rises very rapidly until the 90% position is reached, and that the time from 90% to 100% is relatively great; for this reason the indicators are usually rated by defining the time lag as the interval of time taken to record 90% of any change in load. The time lag depends upon the torque of the electrical element and upon the retarding effort of the permanent magnets; by altering the effect of these two factors, a time lag from one to thirty minutes can be secured. By changing the position of the retarding magnets in an indicator having a definite rating, the time lag may be varied from 10% to 15%.

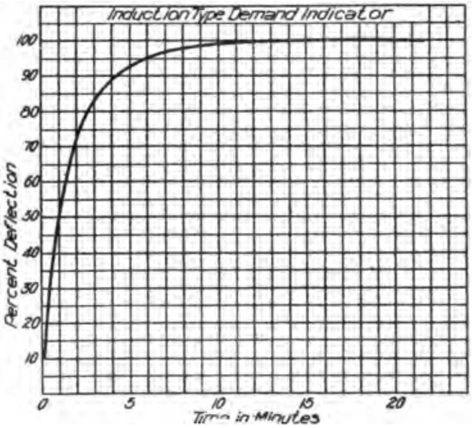


Fig. 79.

The polyphase maximum watt demand indicator can be used on single phase circuits by connecting the potential coils in multiple and the current coils in series and dividing the scale deflection by two.

CHAPTER VII.

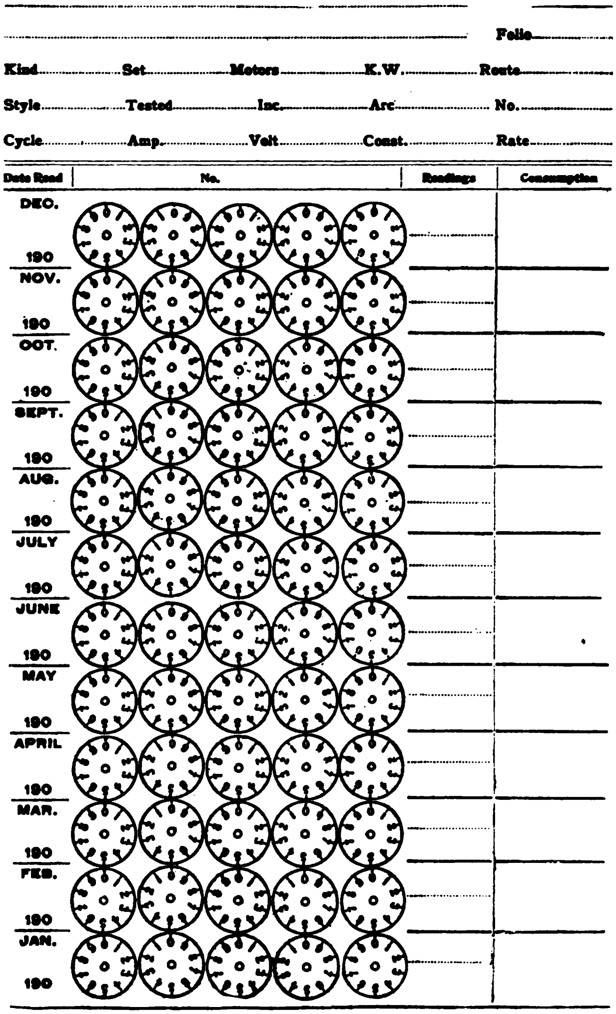
MAINTENANCE AND TESTING.

The care and maintenance of recording watthour meters should receive the most careful attention from distributing companies, and only competent men should be placed in charge of the meter department, because, as pointed out in Chapter I, negligence in the proper care of the meter system may result in a serious financial loss. It is therefore essential that the distributing company be equipped to test and make minor adjustments of its meters. In order to secure the best results it is necessary that some systematic method of inspecting and testing be adopted. Almost all of the larger companies, realizing the importance of meter accuracy, have separate and well-organized meter departments which are equipped for testing, repairing and re-calibrating service meters, this department being held responsible for their proper operation.

With small companies it is often impractical to have a separate meter department, but it will be found, even by the smallest distributing companies, that it is economy in the end to have some systematic method of testing and caring for meters. In small stations, where the size of the system so warrants, it is advisable to employ the entire time of at least one man to see that the meters are kept in proper condition; where this is not warrantable, it can usually be arranged to have the same man do all of the meter work, rather than having two or three men, each doing a part of it, because where there is one man, the responsibility is then definitely placed, and furthermore, he becomes more efficient and he will usually take more interest and pride in seeing that his meters are always in the best of condition.

Reading the Meter and Keeping of Records.

The interval between the readings of each individual meter should be as nearly uniform as possible, because if the interval is greater for one month than it is for the next, the customer's bill will as a rule be



Folio

Kind Set Motors K.W. Route

Style Tested Inc. Arc No.

Cycle Amp. Volt Const. Rate

Date Read	No.	Readings	Consumption
DEC. 190			
NOV. 190			
OCT. 190			
SEPT. 190			
AUG. 190			
JULY 190			
JUNE 190			
MAY 190			
APRIL 190			
MAR. 190			
FEB. 190			
JAN. 190			

Fig. 80.

correspondingly affected, which will in a great many cases lead to dissatisfaction on the part of the consumer, with the resulting annoyance and explanations necessary on the part of the distributing company. The best way in which to obviate such troubles, and to insure a uniformity of meter reading is to begin each month at a fixed date and always have the meter-reader go over the route in the same order.

In reading meters it is usual practice to have a special form of "loose-leaf" book which has on each page twelve (or six) facsimile prints of the meter dial, upon which can be marked the corresponding position of the pointers. Such a card is reproduced in Fig. 80, the reverse side of the card being used for any notes which may be necessary. The meter reader should first note the actual reading of the meter and put the figures down in the column set aside for this purpose; he should then copy the exact positions of all of the pointers. By taking both readings thus, one acts as a check on the other, and with a little practice a man becomes efficient and accurate.

Some distributing companies use the form shown in Fig. 81, which does not provide for the check afforded by having both the direct reading and the positions of the pointers copied. There is a great difference of opinion as to the most advantageous method of transcribing the meter readings to the record book. The objections advanced against the method of copying the positions of the meter pointers is the fact that it takes considerably more time than it does to simply transcribe the numerical value direct; it also involves more work on the part of the book keeping organization, and there is also liability of error when the book-keeper transcribes the reading from the meter reader's book to the record book.

The method of simply transcribing the reading numerically is undoubtedly the most rapid and the most satisfactory if a well experienced and careful man can be employed for this work, but the method of transcribing numerically and also copying the positions of the pointers is usually to be preferred on account of the check which it affords.

Figure 82 represents a very convenient form of file-card which may be used for the office records and

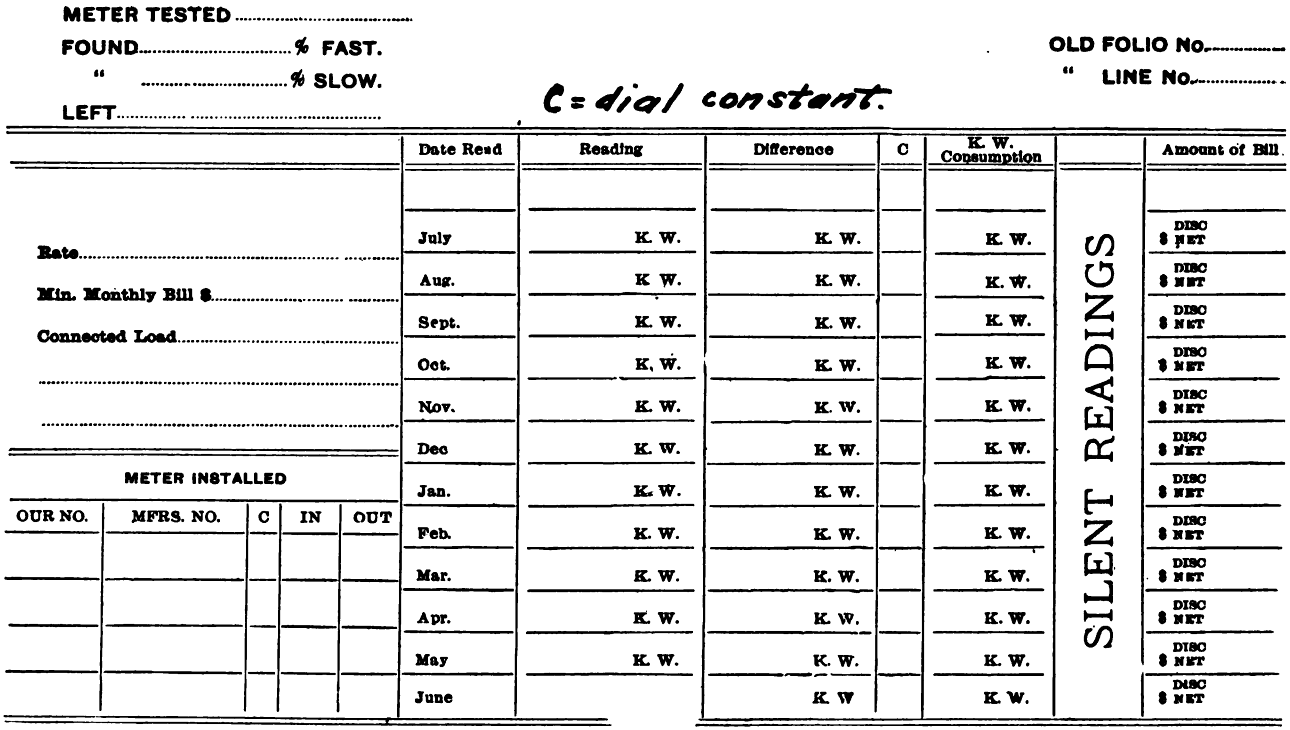
Our No.................C..........Mfgrs. No......................

Location of Meter...

DATE READ	READING	READ BY
JUNE	FORWARDED KW	
JULY	KW	
AUG	KW	
SEPT.	KW	
OCT.	KW	
NOV.	KW	
DEC.	KW	
JAN.	KW	
FEB.	KW	
MAR.	KW	
APR.	KW	
MAY	KW	
JUNE	KW	

Fig. 81.

to which the figures from the reader's book are transferred; the reverse side of the card is similar and the record may be continued thereon. Under no conditions should the record cards be taken from the files.



METER TESTED..............................

FOUND..............................% FAST.

" ....% SLOW.

LEFT..............................

OLD FOLIO No..............

" LINE No..............

C = dial constant.

Rate..............................

Min. Monthly Bill $..............................

Connected Load..............................

....

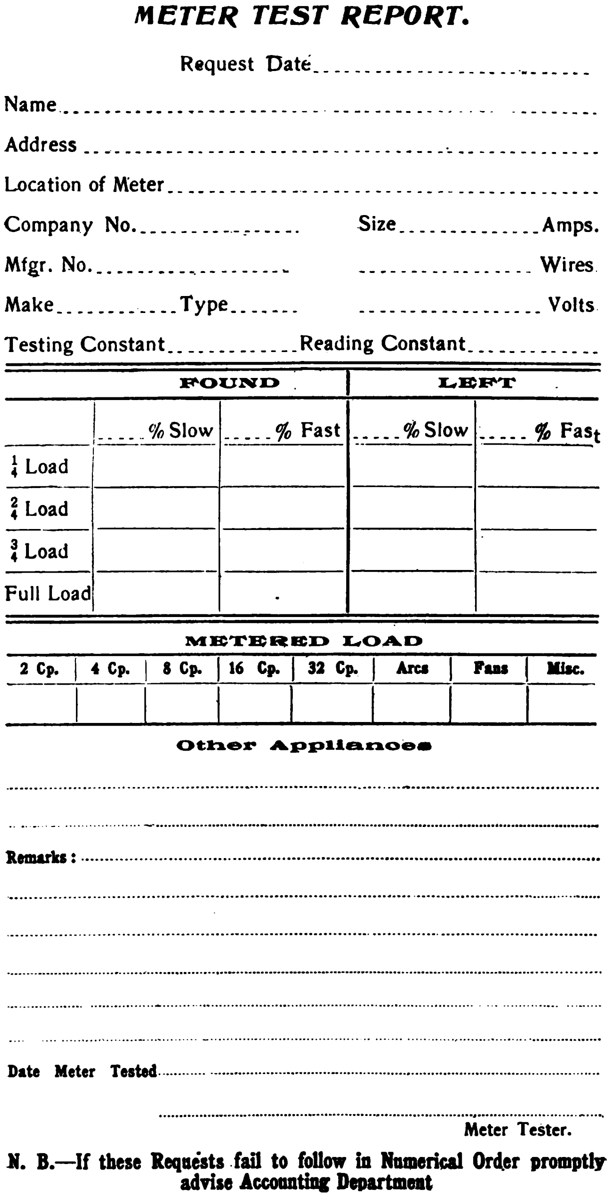
....

METER INSTALLED

OUR NO.	MFRS. NO.	C	IN	OUT

Date Read	Reading	Difference	C	K. W. Consumption		Amount of Bill.
					SILENT READINGS	
July	K. W.	K. W.		K. W.		DISC $ NET
Aug.	K. W.	K. W.		K. W.		DISC $ NET
Sept.	K. W.	K. W.		K. W.		DISC $ NET
Oct.	K. W.	K. W.		K. W.		DISC $ NET
Nov.	K. W.	K. W.		K. W.		DISC $ NET
Dec	K. W.	K. W.		K. W.		DISC $ NET
Jan.	K. W.	K. W.		K. W.		DISC $ NET
Feb.	K. W.	K. W.		K. W.		DISC $ NET
Mar.	K. W.	K. W.		K. W.		DISC $ NET
Apr.	K. W.	K. W.		K. W.		DISC $ NET
May	K. W.	K. W.		K. W.		DISC $ NET
June		K. W.		K. W.		DISC $ NET

Check Meter FIG. 82. **Rented Meter Charge**



METER TEST REPORT.

Request Date..............................

Name..

Address..

Location of Meter..

Company No.................... Size................Amps.

Mfgr. No.................... ....Wires

Make..............Type........ ....Volts

Testing Constant..............Reading Constant..............

	FOUND		LEFT	
	.....% Slow	.....% Fast	.....% Slow	.....% Fast
¼ Load				
2/4 Load				
¾ Load				
Full Load				

METERED LOAD

2 Cp.	4 Cp.	8 Cp.	16 Cp.	32 Cp.	Arcs	Fans	Misc.

Other Appliances

....

....

Remarks: ....

....

....

....

....

....

Date Meter Tested..

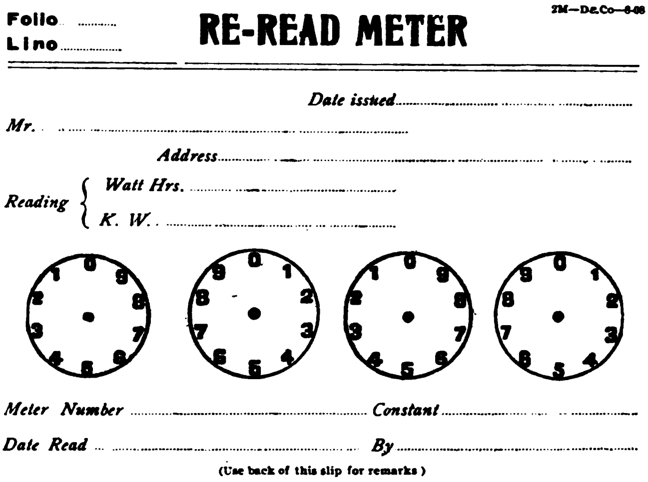
....

Meter Tester.

N. B.—If these Requests fail to follow in Numerical Order promptly advise Accounting Department

Fig. 83a.

It is not infrequent that check readings have to be made, sometimes at the request of the consumer and sometimes because of apparent discrepancies in the monthly reading. When such readings are taken it is advisable to use a "re-read" card of a form similar to that shown at (b) in Fig. 83. Fig. 83 (a) shows a convenient form of record blank for use in testing meters.



Folio ....
Line ....

RE-READ METER

2M—De.Co—6-08

Date issued ....

Mr. ....

Address ....

Reading { *Watt Hrs.* ....
Reading { *K. W.* ....

Meter Number .... *Constant* ....

Date Read .... *By* ....

(Use back of this slip for remarks)

Fig. 83b.

During the regular, or periodic, testing of service meters, there will invariably be found a number of slow meters and it is good policy to use a card similar to Fig. 84, so that the consumer may expect the

Dear Sir:

Your meter located at __________

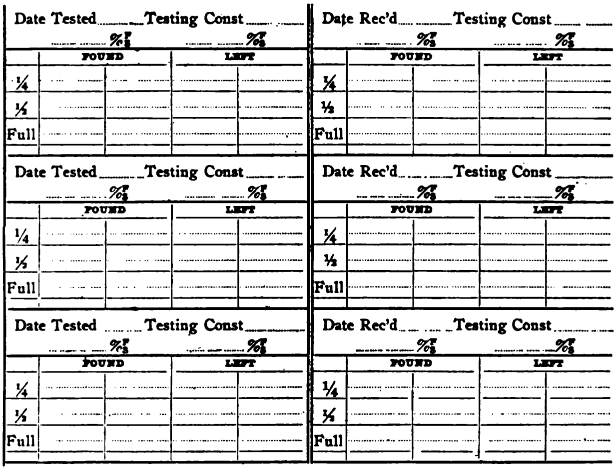
being our No. __________ **upon being tested has been found** __________ **%** **slow. Fearing that any additional billing on your previous consumption would be inaccurate, and possibly unjust to you, we are not rendering any additional bill, but are standing whatever loss has been incurred.**

We trust all this is satisfactory.

Yours truly,

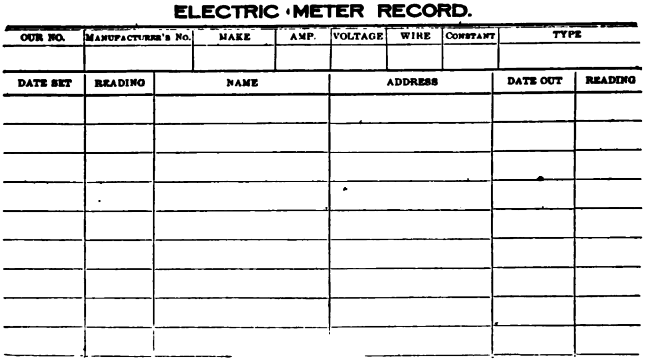
Fig. 84.

next bill to vary from the last one. Such precautions involve very little time and expense, and in many cases they save heated arguments and preserve the good will of the consumer.



Date Tested ______ Testing Const ______	______ %$^{F}_{S}$	______ %$^{F}_{S}$			Date Rec'd ______ Testing Const ______	______ %$^{F}_{S}$	______ %$^{F}_{S}$		
	FOUND		LEFT			FOUND		LEFT	
¼					¼				
½					½				
Full					Full				
Date Tested ______ Testing Const ______	______ %$^{F}_{S}$	______ %$^{F}_{S}$			Date Rec'd ______ Testing Const ______	______ %$^{F}_{S}$	______ %$^{F}_{S}$		
	FOUND		LEFT			FOUND		LEFT	
¼					¼				
½					½				
Full					Full				
Date Tested ______ Testing Const ______	______ %$^{F}_{S}$	______ %$^{F}_{S}$			Date Rec'd ______ Testing Const ______	______ %$^{F}_{S}$	______ %$^{F}_{S}$		
	FOUND		LEFT			FOUND		LEFT	
¼					¼				
½					½				
Full					Full				

Fig. 85a.



ELECTRIC METER RECORD.

OUR NO.	MANUFACTURER'S NO.	MAKE	AMP.	VOLTAGE	WIRE	CONSTANT	TYPE

DATE SET	READING	NAME	ADDRESS	DATE OUT	READING

Fig. 85b

Too much stress cannot be laid upon the systematic keeping of the data regarding the individual performance of the meters, and for this purpose it is advisable to keep record cards similar to that shown in Fig. 85, (a) being the front side and (b) being the reverse side. Such data will give an accurate and ready insight into the continued performance of the individual meters, and will act as a guide in the future selection of the best meter for the service of the existing conditions.

Installation of Meters.

With few exceptions, new meters will be found to be well within the limit of good accuracy, inasmuch as they are carefully tested and adjusted at the factory before they are shipped. Before a meter is installed, however, its accuracy should be checked as a matter of record and in order to make any minor adjustments that may be found to be necessary. (In transporting a meter from place to place it is not at all unlikely that the finer adjustments may be affected.) When installing a meter care should be taken, as far as possible, to select an easily accessible place which is free from vibration, jar and moisture, and a place where it will be protected from the weather; it should be installed in such a position that it can be easily read—a point which is too often overlooked. The meter should not be roughly handled during installation or in carrying it from place to place, as it must be remembered that it is a delicate device and should be handled accordingly.

When putting a meter into service care should be taken to see that the moving element does not rest on the jewel bearing until it is installed and ready for operation. The different makes of meters have different methods of accomplishing this result, but in all of them provision is made for protecting the jewel bearing during transportation.

Before a service meter is put into operation it is necessary to see that it is level, since friction is liable to result if this precaution is not taken. (Some manufacturers furnish a small pocket spirit level for this purpose).

Meters should never be located beneath water pipes nor near steam pipes; they should be placed within 8 feet of the floor line so that the periodic testing may be accomplished with the greatest ease.

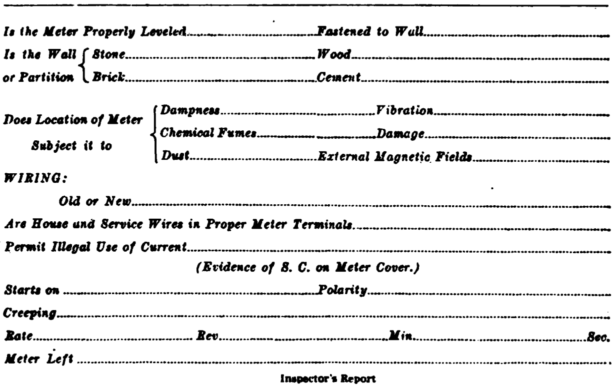
Meters should not be placed closer together than 15 inches between centers; if placed closer than this they may "interfere" with each other through the effects of stray fields.

Meters should not be installed close to conductors carrying heavy currents nor in the vicinity of iron girders or posts.

The subject of "over-metering" has already been mentioned in several places; as a general rule it may here be stated that for residence lighting the meter should have a capacity of approximately 50 per cent of the connected load; for small store lighting, window lighting, out-door multiple arc lamps, etc., the meter should have a capacity of about 90 per cent to 100 per cent of the connected load, while for medium and large sized stores this percentage will be approximately 75 to 80 per cent. For metering a motor load, the meter should usually have a capacity of 100 per cent, except where a number of motors are installed, some of which may be running idle or lightly loaded most of the time, in which case a smaller meter could be used. Occasionally it is necessary to install a meter having a greater capacity than the connected motor load, as for instance in the case of hoists and high speed elevators.

A very convenient and reliable method of leveling meters without the use of a spirit-level consists of placing a coin, such as a quarter of a dollar, on the front of the disc and as near to the edge as possible; if the meter is out of "plumb," the disc will move so as to bring the coin toward the side which is the lowest. The meter can then be leveled so that the disc will remain stationary with the coin resting on the front edge; the coin should then be placed on the edge of the disc in a position ninety degrees from its former position, and the meter then leveled from front to back, without changing the previous adjustment. When the disc is perfectly level, the coin can be placed at any position around the edge, and the disc will remain stationary.

Precaution should be taken to see that the meter is connected properly into the circuit, so that it will rotate in the right direction, especially is this true with polyphase meters, and with single phase meters when used to measure polyphase power. It is not infrequent that two single phase meters are used to measure the power being supplied to polyphase induction motors; the power factor of an induction motor when running lightly loaded is often below 50 per cent, in which case one of the two single phase meters will run backward when properly connected; care should therefore be taken to see that the meters are so connected that both of them will run forward, when the motor is operating at or near full load.



Is the Meter Properly Leveled.................................*Fastened to Wall*.................................

Is the Wall { *Stone*.................................*Wood*.................................

or Partition { *Brick*.................................*Cement*.................................

Does Location of Meter Subject it to { *Dampness*.................................*Vibration*.................................

{ *Chemical Fumes*.................................*Damage*.................................

{ *Dust*.................................*External Magnetic Fields*.................................

WIRING:

Old or New.................................

Are House and Service Wires in Proper Meter Terminals.................................

Permit Illegal Use of Current.................................

(Evidence of S. C. on Meter Cover.)

Starts on ....*Polarity*.................................

Creeping.................................

Rate.................................*Rev*.................................*Min*.................................*Sec.*

Meter Left ....

Inspector's Report

Fig. 86.

The card shown in Fig. 86, illustrates the form of "Inspector's Report" as used by the Pacific Gas & Electric Co., of San Francisco, Cal., the practice of having a report made out like this for all new installations is to be highly recommended.

Testing and Adjusting.

To insure the continued accuracy of any watt hour meter it is necessary that it be tested and adjusted from time to time. In the smaller meters it is not necessary to make these tests oftener than about once a year, except in cases of complaint, and when meters are operating under adverse conditions; in the larger sizes, where a small variation in accuracy represents a considerable amount of money, the tests should of course be made oftener, especially where a meter of large capacity is called upon to register a small percentage of its rated load for a great part of the time. As a rule, the conditions under which the meter operates will dictate in a large measure the frequency of the tests.

The experience of the large number of distributing companies that have adopted some method of systematically testing and adjusting their meters has proven that the increased revenue resulting from more accurate meters has much more than offset the additional expense to which they have been put, besides reducing trouble and complaints due to occasional fast meters.

In testing meters which are in service it is much better to test and make any necessary adjustments at the point of installation, rather than to bring the meter into the testing room, since with the proper instruments the same accuracy can be obtained and a great saving in time can be effected. Such practice also avoids those injuries to the meter which are liable to occur in transportation to and from the customer's premises. Of course, where it is necessary to make repairs, it is best to bring the meter to the shop. That particular part of the meter which usually gives the most trouble and which requires the most frequent renewal is the jewel bearing. Jewels and pivots can be renewed at the point of installation without disturbing the meter. Friction in the jewel bearing will result in the meter running slow, and a new jewel should be substituted whenever a defective one is located. When installing a new jewel, a new pivot or ball should also be installed, as the old one is more than apt to have minute particles of the defective jewel imbedded in it, which will constitute an effective cutting tool and will soon ruin a new jewel. In the case of meters employing the ball and jewel bearing it is best to handle the ball with a pair of tweezers rather than with the fingers, as the moisture from the hands may cause the ball to rust.

There are several accurate methods used for testing watt hour meters, and the choice of the method or methods to be used is usually determined by the relative convenience of that method; the most common are (1) the voltmeter and ammeter method, (2) the indicating wattmeter method and (3) the portable rotating standard method.

Testing with Indicating Instruments.

The voltmeter and ammeter method can only be used with direct current watt hour meters, or with alternating current watt hour meters when the power factor is unity or its exact value known; the connections for this method are shown in Fig. 87, where V is the voltmeter, A is the ammeter and W the single phase watthour meter being tested. If E is the voltage impressed upon the circuit, and I the current in amperes, then the power (unity power factor) is P=E x I.

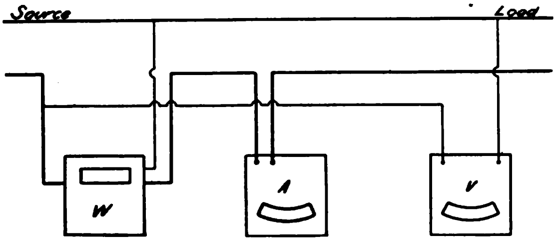


Fig. 87.

The indicating wattmeter method of testing watt hour meters is applicable to alternating currents regardless of what the power factor may be, so with this method the power, P, is read direct. Fig. 88 shows the connections for this method of testing.

Each revolution of the meter disc represents a certain number of watt hours of electrical energy passing through the meter, which is given in some types of meters directly in the form of the meter "constant," and in such meters, if R is the number of revolutions of the disc in t seconds (as measured with a stop watch), and with constant power passing through

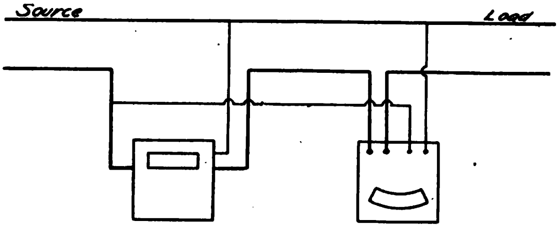


Fig. 88.

the meter, then the watt hours would be $= R \times K$, where K is the meter "constant." But the power P=watt seconds per second=watt hours x 3,600 divided by the time, t, therefore we have

$$P = \frac{R\ K\ 3{,}600}{t}$$

The constant, K, for the General Electric meters will be found marked on the meter disc, and are also reproduced in the accompanying tables.

DIRECT CURRENT METERS.

	100–120 Volt Type C-6				200–240 Volt. 2 and 3 wire. Type C-6				500-600 Volt Type C-7			
Amps.	Meter "K"	Reg. Ratio	Dial Const.	Watts per r.p.m.	Meter "K"	Reg. Ratio	Dial Const.	Watts per r.p.m.	Meter "K"	Reg. Ratio	Dial Const.	Watts per r.p.m.
5	.2	500	none	12	.4	250	none	24	1	100	none	60
10	.4	250	"	24	.75	133.33	"	45	2	50	"	120
15	.6	166.66	"	36	1.25	80	"	75	3	33.33	"	180
25	1.0	100	"	60	2.00	50	"	120	5	20	"	300
50	2.0	50	"	120	4.00	25	"	240	10	10	"	600
75	3.0	33.33	"	180	6.00	16.66	"	360	15	66.66	10	900
100	4.0	25	"	240	7.50	13.33	"	450	20	50	10	1200
150	6.0	16.66	"	360	12.50	80	10	750	30	33.33	10	1800
300	12.5	80	10	750	25.00	40	10	1500	60	16.66	10	3600
600	25.0	40	10	1500	*50.00	*20	10	300	125	80	100	7500

*Applies to 600 amperes, two wire meters only; 600 ampere, three wire meters are not manufactured.

General Electric, Type "I," Standard 60 Cycle, Single Phase Watthour Meters.

	100-130 Volt 2 Wire		200-260 Volt 2 and 3 Wire		500-600 Volt	
Amps.	Meter "K"	Watts per r.p.m.	Meter "K"	Watts per r.p.m.	Meter "K"	Watts per r.p.m.
3	.2	12	.4	24	1	60
5	.3	18	.6	36	1.5	75
10	.6	36	1.25	75	3	180
15	1	60	2	120	5	300
25	1.5	90	3	180	7.5	450
50	3	180	6	360	15	900
75	5	300	10	600	25	1500
100	6	360	12.5	750	30	1800
150	10	600	20	1200	50	3000
200	12.5	750	25	1500	60	3600
300	20	1200	40	2400	100	6000

Polyphase, 60 Type "D-3."

3	.4	24	.75	45	2	120
5	.6	36	1.25	75	3	180
10	1.25	75	2.5	150	6	360
15	2	120	4	240	10	600
25	3	180	6	360	15	900
50	6	360	12.5	750	30	1800
75	7.5	450	15	900	40	2400
100	12.5	750	25	1500	60	3600
150	15	900	30	1800	75	4500

For General Electric meters used with current and potential transformers, but calibrated without them, the constant to be used is that marked on the meter disc, divided by the product of the ratios of the potential and current transformers. The worm reduction in all General Electric meters is 100 and will be found stamped on the back of the register. The register ratio multiplied by 100=number of revolutions of disc for one revolution of the right hand pointer. In all cases, the meter, K, is the actual number of watt hours per revolution of the disc.

$$\text{Meter Constant, } K = \frac{{}^{*}\text{Rating in (volt-amperes)}}{\text{Full load r.p.m. of disc} \times 60}$$

$$\text{Register Ratio} = \frac{\text{Watt hours of right hand dial}}{\text{Worm reduction} \times K}$$

(*For polyphase meters, the rating should be multiplied by 2. In case a meter has a double rating, such as 110/220 volts, the latter voltage should be applied in the formula. The approximate full load speed of all G. E. type "I" and "D-3," 60 cycle meters is 30 r.p.m.)

Westinghouse Meter Constants.

For different makes of meters, the testing formula given takes a different form since the constant K is made to embrace different factors.

For the Westinghouse meter, the formula becomes

$$P = \frac{R \times K}{t}$$

where K represents the **watt-seconds** for one revolution of the meter disc.

The values of the constant, K, for the Westinghouse types B and C and for the direct current meters are as follows:

2-wire D. C. and self-contained single phase, K = volts x amps x 2.4;

2-wire single phase used with *current* transformers *only* (but checked without), K = volts x 5 x 2.4;

2-wire, single phase used with *current* and *potential* transformers (but checked without), K = 5 x 100 x 2.4;

2-wire, single phase, used with transformers of either or both forms (and checked with), K = volts x amps x 2.4;

3-wire, single phase, self-contained, K = volts x amps. x 4.8.

3-wire, single phase, used with current transformers (but checked wtihout), K = volts (as marked on meter) x 12;

Type "C" polyphase, self-contained, K = volts x amps x 4.8;

Type "C" polyphase, used with *current* transformers only (but checked without), K = 5 x volts x 4.8;

Type "C" polyphase, used with current and potential transformers (but checked without), K = 2400;

Type "C" polyphase used with transformers of either or both forms (and checked with), K = volts x amps x 4.8.

In all cases, the volt and ampere values referred to are those as marked on the name plate of the meter. The full load speed of the types B and C is 25 r.p.m. For the Westinghouse type A meter, the full load speed is 50 r.p.m., and the constant, K, for this type is exactly one-half the value of a similarly rated type C meter.

Fort Wayne Type K Meter.

The calibrating equation of the Fort Wayne type K meter is as follows:

$$P = \frac{R \times K \times 100}{t}$$

where t is the time in seconds during which the meter makes R revolutions, and where K is the constant, which will be found in the following tables:

**Fort Wayne, Type "K," Single Phase, 60 Cycle Watthour Meters whose Serial Number is 344,999 or less.
Values of the Constant, K.**

Amps.	2 wire 50 volt	2 wire 110 volt	2 wire 220 volt	3 wire 220 volt	2 wire 550 volt	2 wire 1100 volt	2 wire 2200 volt
3	..	9	18	18	45	90	90
5	9	9	18	18	45	90	180
7.5	..	..	..	27	..	..	..
10	9	18	36	36	90	180	360
15	18	36	54	54	180	360	540
20	18	36	72	72	180	360	720
25	18	36	72	72	180	360	900
30	36	72	90	90	360	720	1080
40	36	72	108	108	360	720	1440
50	36	72	144	144	360	720	1800
60	54	108	180	180	540	1080	2160
75	54	108	216	216	540	1080	2700
100	72	144	288	288	720	1440	3600
125	90	180	360	360	900	1800	4500
150	108	216	432	432	1080	2160	5400
200	144	288	576	576	1440	2880	7200
250	180	360	720	720	1800	3600	9000
300	270	540	1080	1080	2700	5400	10800
400	360	720	1440	1440	3600	7200	14400
500	450	900	1800	1800	4500	9000	18000
600	540	1080	2160	2160	5400	10800	21600
800	720	1440	2880	2880	7200	14400	28800
1000	900	1800	3600	3600	9000	18000	36000
	Use These Constants for High Torque Meters.						
15	13.5	27	54	54	135	270	540
30	27.0	54	90	90	270	540	1080

Fort Wayne, Type "K," Single Phase, 60 Cycle Watthour Meters, whose Serial Number is 345,000 or above.

Values of the Constant, K.

Amps.	2 wire 110 volt	2 wire 220 volt	3 wire 220 volt	2 wire 440 volt	2 wire 550 volt	2 wire 1100 volt	2 wire 2200 volt
5	9	18	18	36	45	90	180
10	18	36	36	72	90	180	360
15	27	54	54	108	135	270	540
20	36	72	72	144	180	360	720
25	45	90	90	180	225	450	900
40	72	144	144	288	360	720	1440
50	90	180	180	360	450	900	1800
75	135	270	270	540	675	1350	2700
100	180	360	360	720	900	1800	3600
125	225	450	450	900	1125	2250	4500
150	270	540	540	1080	1350	2700	5400
200	360	720	720	1440	1800	3600	7200
300	540	1080	1080	2160	2700	5400	10800
400	720	1440	1440	2880	3600	7200	14400
600	1080	2160	2160	4320	5400	10800	21600
800	1440	2880	2880	5760	7200	14400	28800

Fort Wayne, Type "K," Polyphase Meters whose Serial Number is 344,999 or less.

Values of the Constant K.

Amps.	110 v.	220 v.	440 v.	550 v.	1100 v.	2200 v.
3	18	36	72	90	180	360
5	36	72	144	180	360	720
10	72	144	288	360	720	1440
15	108	216	432	540	1080	2160
20	144	288	576	720	1440	2880
25	144	288	576	720	1800	3600
30	216	360	720	1080	2160	4320
40	288	576	1152	1440	2880	5760
50	288	576	1152	1440	3600	7200
60	432	864	1728	2160	4320	8640
75	432	864	1728	2160	5400	10800
100	576	1152	2304	2880	7200	14400
125	720	1440	2880	3600	9000	18000
150	864	1800	3600	4320	10800	21600
200	1440	2880	5760	7200	14400	28800
250	1800	3600	7200	9000	18000	36000
300	2160	4320	8640	10800	21600	43200
400	2880	5760	11520	14400	28800	57600
500	3600	7200	14400	18000	36000	72000
600	4320	8640	17280	21600	43200	86400
800	5760	11520	23040	28800	57600	115200
1000	7200	14400	28800	36000	72000	144000

Fort Wayne, Type "K" Polyphase Meters whose Serial Number is 345,000 or above.
Values of the Constant, K.

Amps.	110 v.	220 v.	440 v.	550 v.	1100 v.	2200 v.
5	36	72	144	180	360	720
10	72	144	288	360	720	1440
15	108	216	432	540	1080	2160
25	180	360	720	900	1800	3600
50	360	720	1440	1800	3600	7200
75	540	1080	2160	2700	5400	10800
100	720	1440	2880	3600	7200	14400
150	1080	2160	4320	5400	10800	21600
200	1440	2880	5760	7200	14400	28800
300	2160	4320	8640	10800	21600	43200
400	2880	5760	11520	14400	28800	57600
600	4320	8640	17280	21600	43200	86400
800	5760	11520	23040	28800	57600	115200

The Duncan Meter.

The formula for testing meters manufactured by the Duncan Electric Manufacturing Company is

$$P = \frac{R \times K \times 3600}{t}$$

which is the same as that previously given for the General Electric meter. The following is a table of testing constants:

	110 Volts		220 Volts		550 Volts	
Amps.	Meter "K"	Watts per r.p.m.	Meter "K"	Watts per r.p.m.	Meter "K"	Watts per r.p.m.
2.5	0.25	15	0.5	30	1	60
5	0.25	15	0.5	30	1	60
7.5	0.50	30	1	60	2	120
10	0.50	30	1	60	2	120
15	1	60	2	120	5	300
25	1	60	2	120	5	300
50	2	120	4	240	10	600
75	3	180	6	360	16	960
100	4	240	8	480	20	1200
150	6	360	12	720	30	1800
200	8	480	16	960	40	2400
300	12	720	25	1500	60	3600
450	20	1200	30	1800	80	4800
600	25	1500	50	3000	100	6000
800	30	1800	60	3600	160	9600

Sometimes it is necessary to use the formula already given for the determination of other values than the watts, P, and for convenience this formula is rewritten as follows:

(1) $\text{Number of revolutions} = \dfrac{\text{Secs. during test x watts indicated}}{\text{3600 x testing constant (K)}}$

(2) $\text{Testing constant} = \dfrac{\text{seconds during test x watts indicated}}{\text{3600 x revolutions.}}$

(3) $\text{Seconds} = \dfrac{\text{3600 x revolutions x testing constant}}{\text{watts indicated}}$

The Sangamo Mercury Meter.

A description of the Sangamo Mercury Meter will be found in Chapter V., the table of calibrating constants being given below:

Amps.	100/125 volts.	200/250 volts.	500/600 volts.
5 A. C.	1,800	3,600	....
5 D. C.	2,400	4,800	12,000
10	2,400	4,800	12,000
20	4.800	9,600	24,000
30	7,200	14,400	36,000
40	9,600	19,200	48,000
60	14,400	28,800	72,000
80	19,200	38,400	96,000
100	24,000	48,000	120,000
150	36,000	72,000	180,000
200	48,000	96,000	240,000
300	72,000	144,000	360,000
400	96,000	192,000	480,000
500	120,000	240,000	600,000
600	144,000	288,000	720,000
800	192,000	384,000	960,000
1000	240,000	480,000	1,200,000

The calibrating equation for the Sangamo is the same as for the Westinghouse meter, viz.:

$$P=\frac{R\times K}{t},$$

in which the constant, $K =$ watt-seconds recorded by one revolution of the disc.

Larger capacity meters than given in the above table have proportionally greater values of K.

Three wire 110-220 volts A. C. meters have same constants as above given for the 200-250 volt meters.

Testing with the Portable Rotating Standard.

The third method of testing watthour meters, and probably the most convenient and the quickest for outside work, consists in using a portable standard watt hour meter, which is usually known as a "rotating standard." It is especially well adapted for the rapid testing of service meters at the point of installation. The portable standard eliminates the necessity of a stop watch, since the time element does not enter into account; furthermore, the load does not have to remain constant during the test, as is the case with both of the previously named methods; the only thing which has to be observed is the number of revolutions of the disc of the meter under test; the disc of the rotating standard is directly connected to the large or lowest reading pointer, and therefore indicates the actual number of revolutions which it makes. Figure 89 shows interior and exterior view of a typical type of rotating standard test meter. This type of meter is essentially an ordinary watthour meter with certain modifications. It is made with several different current coils whose leads are brought out to a connection block on the top of the meter or to a drum switch within, and that coil whose capacity is nearest the value at which the meter under test is operating can be connected in the circuit. By this means the test meter can always be made to operate at or near full load, therefore having its full load accuracy throughout a wide range. This is an excellent feature, as it insures accuracy over a wide range and also permits the use of one test meter for calibrating watthour meters of various sizes.

Fig. 89.

The rotating standard is made self-contained in the following sizes: Direct current, 110-220 volts, with current coils for 1, 2, 10, 20 and 40 amperes, or with current coils for 5, 10, 50 and 100 amperes; alternating current, 110-220 volts, with current coils for 1, 10 and 20 amperes, or with current coils for 1, 5, 10, 50 and 100 amperes. By means of "multipliers" or potential transformers, these instruments can be used on 440 and 550 volts.

The rotating standard is very carefully designed and is well built mechanically. The registering mechanism is simple, since, as previously stated, the disc shaft is directly connected to the lowest reading pointer. The complete dial is usually made up of two pointers, the ratio being such that the highest reading pointer will not repeat its reading within less time than about two and one-half minutes when operating at full load speed. The number of revolutions of the disc as indicated by the pointers, multiplied by the constant for the particular coil of the standard which is connected in circuit, gives the watt hours that have passed during the time it is connected to the circuit, or

$P = R \times K$ (Gen. Elec. Rotating Standard).

The accuracy of the meter under test is expressed by the following equation:

$$\text{Percentage of accuracy} = \frac{r \times k}{R \times K} \times 100, \text{ where}$$

r=revolutions of disc of meter under test;
k=constant of meter under test;
R=revolutions of rotating standard as indicated by register;
K=constant of coil being used in standard.

For General Electric meters, k is marked on the disc.

For Westinghouse meters, $k = \frac{c \times \text{watt rating}}{3600}$, where c is the value of the constant for Westinghouse meters.

For Fort Wayne meters, $k = \frac{c}{36}$, where "c" is the value of the constant as given for Fort Wayne meters.

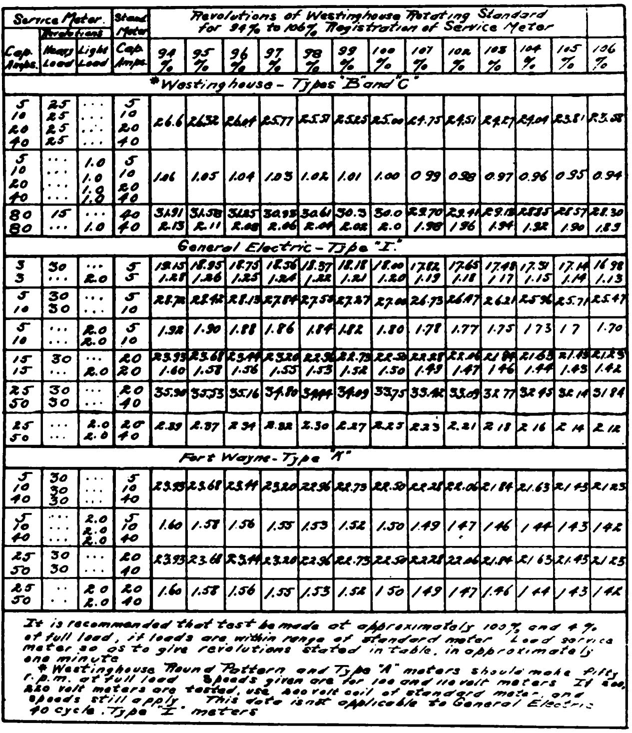
In the case of the rotating standard, the value of the constant K for the individual coils is the same as in the standard service meters. For instance, the value of K for the 10-ampere coil in the rotating standard is the same as the constant for a 10-ampere service meter, so that when testing service meters with a rotating standard and at the same time using the coil of the standard meter which is of the same capacity as the meter under test, is is only necessary to compare the revolutions of the two meters, that is:

$$\text{Percentage of accuracy} = \frac{r}{R} \times 100, \text{ or the}$$

$$\text{Percentage of error} = \frac{r - R}{R} \times 100, \text{ where}$$

r=revolutions of the meter under test, and R= revolutions of standard.

Below is given a table of data to be used with the Westinghouse rotating standard when used in checking induction meters manufactured by the Westinghouse Company, the General Electric Company and the Fort Wayne Electric Works:



Service Meter			Stand. Meter	Revolutions of Westinghouse Rotating Standard for 94% to 106% Registration of Service Meter												
Cap. Amps.	Revolutions Heavy Load	Light Load	Cap. Amps.	94 %	95 %	96 %	97 %	98 %	99 %	100 %	101 %	102 %	103 %	104 %	105 %	106 %
*Westinghouse - Types "B" and "C"																
5 10 20 40	25 25 25 25	... ...	5 10 20 40	26.6	26.32	26.04	25.77	25.51	25.25	25.00	24.75	24.51	24.27	24.04	23.81	23.58
5 10 20 40	... ...	1.0 1.0 1.0 1.0	5 10 20 40	1.06	1.05	1.04	1.03	1.02	1.01	1.00	0.99	0.98	0.97	0.96	0.95	0.94
80 80	15 ...	... 1.0	40 40	31.91 2.13	31.58 2.11	31.25 2.08	30.93 2.06	30.61 2.04	30.3 2.02	30.0 2.0	29.70 1.98	29.41 1.96	29.13 1.94	28.85 1.92	28.57 1.90	28.30 1.89
General Electric - Type "I."																
3 3	30 ...	... 2.0	5 5	19.15 1.28	18.95 1.26	18.75 1.25	18.56 1.24	18.37 1.22	18.18 1.21	18.00 1.20	17.82 1.19	17.65 1.18	17.48 1.17	17.31 1.15	17.14 1.14	16.98 1.13
5 10	30 30	... ...	5 10	28.72	28.42	28.13	27.84	27.55	27.27	27.00	26.73	26.47	26.21	25.96	25.71	25.47
5 10	... ...	2.0 2.0	5 10	1.92	1.90	1.88	1.86	1.84	1.82	1.80	1.78	1.77	1.75	1.73	1.7	1.70
15 15	30 ...	... 2.0	20 20	23.93 1.60	23.68 1.58	23.44 1.56	23.20 1.55	22.96 1.53	22.73 1.52	22.50 1.50	22.28 1.49	22.06 1.47	21.84 1.46	21.63 1.44	21.43 1.43	21.23 1.42
25 50	30 30	... ...	20 40	35.90	35.53	35.16	34.80	34.44	34.09	33.75	33.42	33.09	32.77	32.45	32.14	31.84
25 50	... ...	2.0 2.0	20 40	2.39	2.37	2.34	2.32	2.30	2.27	2.25	2.23	2.21	2.18	2.16	2.14	2.12
Fort Wayne - Type "K"																
5 10 40	30 30 30	... ...	5 10 40	23.93	23.68	23.44	23.20	22.96	22.73	22.50	22.28	22.06	21.84	21.63	21.45	21.25
5 10 40	... ...	2.0 2.0 2.0	5 10 40	1.60	1.58	1.56	1.55	1.53	1.52	1.50	1.49	1.47	1.46	1.44	1.43	1.42
25 50	30 30	... ...	20 40	23.93	23.68	23.44	23.20	22.96	22.73	22.50	22.28	22.06	21.84	21.63	21.45	21.25
25 50	.. ..	2.0 2.0	20 40	1.60	1.58	1.56	1.55	1.53	1.52	1.50	1.49	1.47	1.46	1.44	1.43	1.42

It is recommended that test be made at approximately 100% and 4% of full load, it loads are within range of standard meter. Load service meter so as to give revolutions stated in table, in approximately one minute.

* Westinghouse Round Pattern and Type "A" meters should make fifty r.p.m. at full load. Speeds given are for 100 and 110 volt meters. If 200, 220 volt meters are tested, use 200 volt coil of standard meter, and speeds still apply. This data isnot applicable to General Electric 40 cycle. Type "I" meters

Fig. 90

The constant of any coil of the Westinghouse rotating standard is the same as the constant of a Westinghouse service meter having the same ampere capacity as that coil, so that the meter under test and the standard should make the same number of revolutions if the meter under test is correct.

The general connections of the test meter are shown in Figure 91. After the connections have all been made the meter is started and stopped by simply closing or opening the little push button switch, S. The meter tester has only to close the potential circuit by means of this switch, note the number of revolutions made by the standard and by the meter under test and apply these values in the above formula, from which he can immediately obtain the percentage accuracy of the meter under test. If it is found to be too fast or too slow it should be adjusted as previously explained. Meters should be adjusted for accuracy both on full load and about 5 per cent load, and it should be within 2 per cent correct throughout this range.

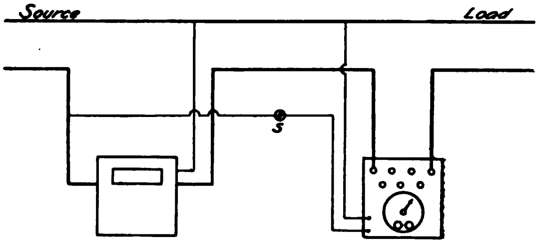


Fig. 91.

In using a portable rotating standard it should be remembered that it must be calibrated from time to time by checking it against laboratory standards.

When testing meters at the point of installation it is usually more convenient to have some kind of a "portable load," which will consist of a lamp bank or other resistance suitably mounted so that it may be carried from place to place, rather than to use the customer's load for testing purposes. With the "portable load" the tester can do his work quicker and he can get the exact load which he desires to put on the meter under test.

Phantom Loads.

A method of testing watthour meters under full load conditions with a small consumption of power is to connect the potential circuit of the meter in the usual way and connect the current coils in series with the secondary of a small transformer especially designed for this purpose, the primary of the transformer being connected in parallel with the line as shown in Fig. 92, thus having the same potential impressed upon it as upon the potential coil of the meter. The resistance (R) is connected in series with the secondary windings, so that portions of it can be short circuited by means of suitable plugs or switches in order that the desired current may be obtained. If the trans-

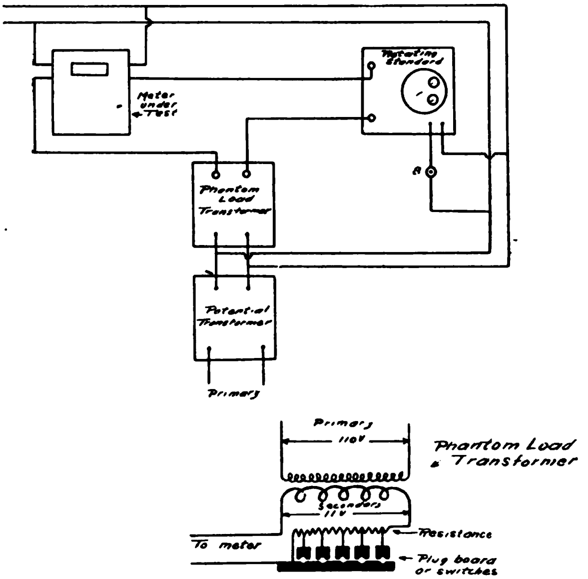


Fig. 92.

former is properly designed and the connections properly made, the secondary current flowing through the current coils of the meter will be approximately in phase with the impressed e.m.f. Full load current or desirable portions of full load current can be obtained for the meter under test, while the primary circuit takes only a very small amount of current from the line. This method of testing is especially convenient in testing meters on high potential circuits, as the potential transformers ordinarily used can also be made to supply the current for testing purposes through the agency of this "phantom load transformer." Such a transformer is usually designed to take about one-half ampere at 110 volts, while supplying 5 amperes to the meter under test.

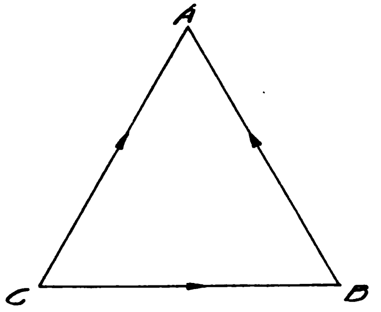


Fig. 93.

The "phantom load transformer" is small and compact and can be easily carried from place to place; in connection with the portable rotating standard it furnishes a very complete set for testing the average size service meter. This transformer can be very advantageously used for testing meters on 50 per cent power factor where three-phase current is available, which is always the case where this adjustment is most important, namely on three-phase power circuits. Let Figure 93 represent the vector diagram of the voltages in a three-phase system; then if the voltage AC is impressed upon the potential winding of the meter, and the primary of the phantom load transformer is connected across BA or BC, the current flowing in the secondary of the transformer, and therefore through the meter windings, will be 60 degrees out of phase with the voltage AC, or in other words, we will have a power factor of 50 per cent. One of the connections referred to will give a 50 per cent leading power factor and the other will give a 50 per cent lagging power factor, but it is better to make any necessary adjustments on lagging power factor, as the meter usually operates under this condition.

To distinguish between the connection for leading power and lagging power factor, most of the resistance in the secondary circuit of the phantom load transformer is short circuited and a reactance cut into the circuit. This reactance causes the current in the secondary to lag behind the secondary e.m.f., and when the primary of the transformer is connected across the proper lines to give a lagging power factor in the meter under test, the current will lag more than 60 degrees, and the power factor will therefore be less than 50 per cent, while if connected to the proper lines for leading power factor the current will lag less than 60 degrees and the power factor will therefore be more than 50 per cent, thereby causing the meter to run slower when the transformer is connected across the proper lines for lagging power factor; as soon as this is determined the reactance is switched out, the power factor then being approximately 50 per cent lagging, after which the test may be continued.

The Knopp Method of Meter Testing.

A method in use by the Pacific Gas & Electric Co., of San Francisco, Cal., for testing watthour meters, and known as the "Knopp method" is as follows:

The tester is provided with a portable resistance box upon which is mounted an indicating ammeter, illustration of which is shown in Fig. 94 (a); he is also supplied with a stop watch which has a special dial that indicates millihours rather than seconds; the large hand (corresponding to the second hand of the ordinary stop watch) of this watch makes one revolution in 36 seconds, the dial being divided into 100 equal parts, each division representing 1-10 millihour. The resistance box has several coils, different combinations of which are used for different loads, each coil being adjusted to consume a definite amount of power at a predetermined potential. The box also has a variable resistance in series with the loading resistance, which can be varied by means of a sliding contact provided for that purpose. By the use of this variable resistance the voltage drop across it may be made equal to the difference between the line voltage and the predetermined (100 volts) voltage, or in other words, so that this voltage is impressed upon the load resistance regardless of the value of the line voltage, which condition when reached will be indicated by the ammeter; that is, for any coil the ammeter will indicate a certain definite current. The potential tap for the watthour meter is connected inside of the resistance box so that the voltage impressed upon the meter will be the same as that impressed upon the load coils.

Fig. 94a.

The load coils of the portable resistance box are adjusted to consume such an amount of power that the meter to be tested will, if correct, make one, ten or twenty revolutions in 36 seconds, or during one complete revolution of the hand of the special millihour watch. All that the meter tester has to do, therefore, is to connect in the box, obtain the proper current (by means of the various resistances), as indicated by the ammeter, and then note the time with the special stop watch of one, ten or twenty revolutions of the meter disc, depending upon which load the meter is being tested. From the reading of the stop watch the accuracy of the meter can be obtained directly without the use of a formula. If the watch has made exactly one revolution (for the load chosen), the meter is correct, while if the hand of the watch lacks two divisions the meter is approximately 2 per cent fast, or if the hand has made a complete revolution and two divisions past, the meter is approximately 2 per cent slow. This method of testing service watthour meters is convenient, since the outfit is light and compact, and it is also very quick.

Figure 94 (b) shows the diagram of connections of the "Knopp set," the name being derived from the patentee, Mr. Otto A. Knopp. For testing 110-volt meters, the plugs o, a, b and c are used, and for testing 220-volt meters the plugs o′, a′, b′, c′ and d are used. An example of the method of using this set is as follows: Suppose that it is desired to test a 5-ampere, 110-volt induction watthour meter having a calibrating constant of .3. The box is connected into circuit and a resistance is plugged in to give 600 watts; the variable resistance is adjusted until the ammeter indicates 0.600 ampere (1-10 of the current passing in shunt through the ammeter). The time for 20 revolutions of the disc is taken with the millihour watch; the time taken for the 20 revolutions should be the same as taken for one revolution of the hand of the watch. The percentage error will be indicated by the watch, as has already been explained. When the meter has been adjusted for full load (600 watts approximately), another resistance which takes 30 watts is plugged into circuit and the 600-watt load cut out; the variable resistance

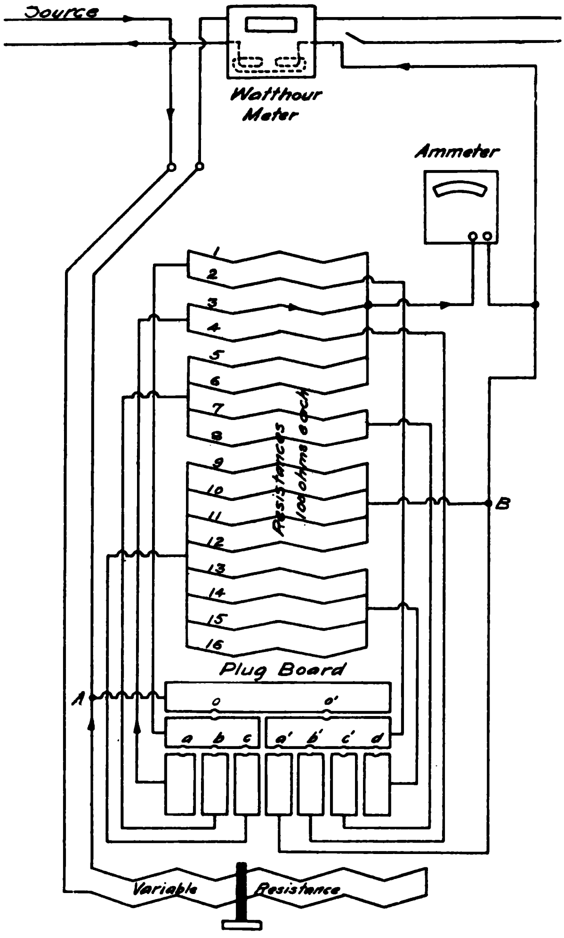


Fig. 94b.

is adjusted until the ammeter indicates 0.30 ampere; if the meter is correct the disc will make one revolution while the hand of the millihour watch makes one revolution.

The voltage of the circuit can be read with this outfit by switching in the 1-ampere resistance coil and cutting the variable resistance entirely out. The 1-ampere coil has a resistance of 100 ohms, and when the line voltage is impressed upon this resistance which is in series with the ammeter (which is 1.5 amperes capacity), the voltage of the circuit can be read directly from the ammeter. Thus if the line voltage is 100, the ammeter will indicate 1.0 ampere or if the line voltage is 110 the ammeter will indicate 1.10 amperes, etc.

By referring to the diagram (Figure 94), it will be seen that for the higher loads the ammeter is connected in shunt with the resistances, thereby taking only a part of the total current. By employing this method of connection, the ammeter is only used over the most accurate part of the scale while testing watt hour meters of different sizes and at different loads.

The Knopp millihour watch can also be used to advantage when testing with ordinary indicating instruments, since it has the advantage of simplifying the testing formula to some extent; the formula

$$P = \frac{R \text{ x } K \text{ x } 3600}{t}, \text{ becomes } P = \frac{R \text{ x } K \text{ x } 1000}{t'},$$

where t' is the time is millihours as read with the special stop watch.

When calibrating meters in the testing room with this special watch the load can be adjusted to be such a multiple of the disc constant that the disc will make one, ten or twenty revolutions for one revolution of the hand of the stop watch when the meter is correct. If the meter is not correct, the percentage inaccuracy will be indicated by the watch. Thus, if the meter is fast the watch hand will not quite make a complete revolution, while if the meter is slow the hand will make more than a complete revolution.

The number of divisions which the hand lacks of a complete revolution is the percentage by which the meter is fast. The number of divisions by which the hand has passed a complete revolution is the percentage by which the meter is slow.

In using this method of testing, the proper load is obtained from the following formula:

$$P = \frac{R \times K \times 10000}{t'},$$

$Pt' = R \times K \times 10000$; for one revolution of the stop-watch hand, $t' = 100$, therefore

$$100\ P = R \times K \times 10{,}000,$$
$$\text{or } P = R \times K \times 100.$$

For a 5-ampere meter having a constant of $K = .3$, and using one revolution of the disc for light load test gives $P = 30$ watts. For full load test taking $R = 20$, we will get $P = 600$ watts.

Portable Testing Set for Direct Current Watt Hour Meters.

For outside testing of direct current meters the set as shown diagramatically in Figure 95, will be found to be convenient; it is compact and light, therefore easy for the tester to carry from place to place. The current is furnished for the smaller sizes of meters (5, 10 and 15 amperes), from an ordinary dry cell, and for larger meters from the improved type of Edison storage battery, the current being regulated by the plug resistances. The potential is taken from the line through the variable resistance which is regulated by a sliding contact block. Potential and current are supplied alike to the watthour meter under test and to the combination volt-ampere indicating meter shown at the top of the diagram. For convenience of testing, the volt-ampere meter has several potential and current ranges. The volt-ampere meter also indicates watts, the indication being shown on a scale directly beneath the intersection of the volt needle and the ampere needle. After selecting the proper current as indicated by the combination meter, the wattage is held constant by means of the variable potential resistance.

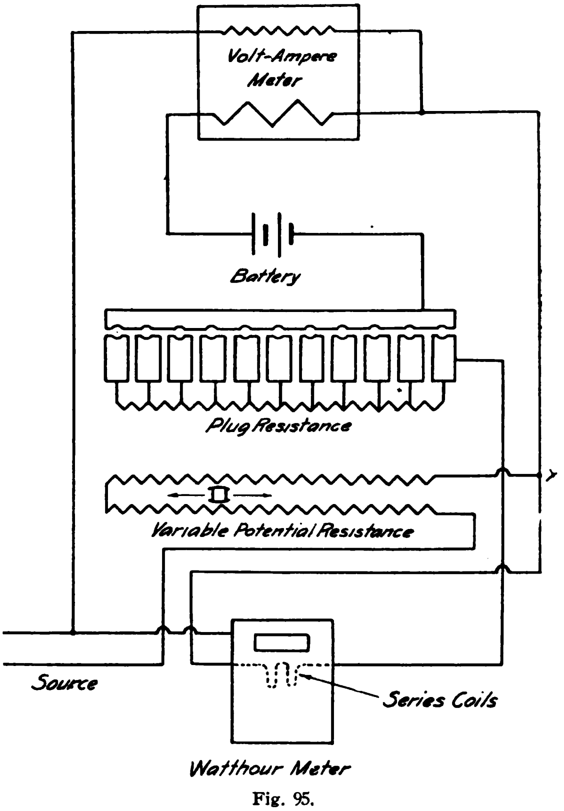

Volt-Ampere Meter
Battery
Plug Resistance
Variable Potential Resistance
Source
Series Coils
Watthour Meter

Fig. 95.

Adjustments.

In any type of meter if the actual value of P (in above formula) is greater than that expressed by the calibrating equation the meter under test is slow, and if this value is less the meter is fast. If we represent the power as registered by the watthour meter by P′, and the true power as indicated by the standard by P, the error in percentage may be expressed by the equation, error $= \frac{P - P'}{P} \times 100$. In calibrating watthour meters it will be found to be more convenient to use the term "percentage of accuracy" or "correction factor" rather than the term "percentage error," since the former method involves less work in making the computations. For example:

$$\text{Percentage of accuracy} = \frac{P'}{P} \times 100,$$

$$\text{Correction factor} = \frac{P}{P'}$$

If the percentage of accuracy is less than 100 the meter is slow; if it is greater the meter is fast. If the correction factor is less than 1 the meter is fast, and if it is more than 1 the meter is slow.

If the watthour meter under test is found to be inaccurate at or near full load, the retarding magnets should be adjusted until the meter registers correctly. If it is slow, the magnets should be moved in toward the center of the disc, which operation will increase the speed, while if the meter is fast the retarding magnets should be moved out toward the periphery of the disc.

If the meter under test is found to be slow on light loads, undue friction should be looked for and eliminated, and the light load adjustment (as previously explained for various kinds of meters) reset. If the meter is fast on very light loads, or if it "creeps," the light load adjusting device is very probably exerting too much torque, and its effect should be decreased until the meter is within 2 per cent accuracy on a 5 per cent load.

Shop Methods of Testing.

A very convenient and flexible laboratory testing board is shown diagrammatically in Fig. 96, which can be used for testing single phase watthour meters of voltages from 100 to 500 inclusive, and of any ampere capacity, the load being regulated by switching more or less of the lamps in circuit by means of the single pole switches, L. The indicating wattmeter may be of 5 or 10 ampere capacity, and can be conveniently mounted in a horizontal position on a swinging bracket; the current transformer being of a 5 or 10 to 1 ratio, or if desired, several current transformers of different ratios may be used. For testing 110-volt watthour meters of capacities not greater than the capacity of the indicating wattmeter, the d.p.d.t. switch S″ is thrown in the downward position, thus putting potential on the 100-volt tap of the indicating wattmeter and on the potential winding of the watt hour meter through the variable resistance; at the same time the t.p.d.t. switch S′ is thrown down, thus connecting the indicating wattmeter directly into the circuit. By throwing S′ up, the current transformer is connected into circuit when it is desired to test higher capacity meters. The correct load, as near as possible, is ob-

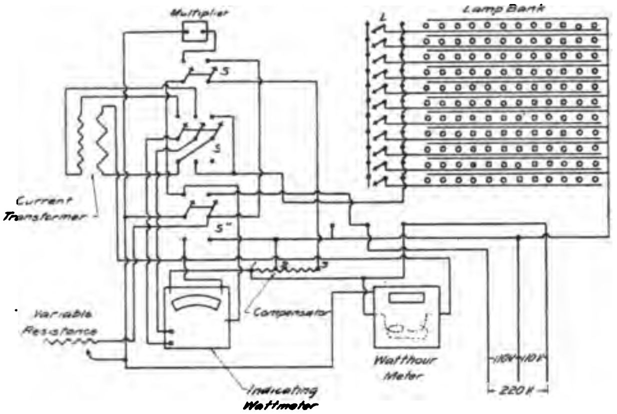


Fig. 96.

tained by closing the switches L, and a finer adjustment is accomplished by means of the variable resistance shown in the diagram. This variable resistance is most conveniently made up by wrapping a bare resistance wire on a suitable mandrel and having a sliding contact which will not interrupt the circuit in passing from one turn of the wire to the next. By means of this variable resistance, the tester can hold the load on the wattmeter constant while the test is being made.

For testing 200-volt meters, the switch S″ is thrown in the upward position, and S′ is thrown down or up according to whether the meter in test is below or above the capacity of the indicating wattmeter.

For testing 500-volt meters the switch S is closed, which puts the potential winding of the watt hour meter directly across the 500-volt tap of the compensator, at the same time putting the potential coil of the indicating wattmeter across the 500-volt circuit in series with the multiplier.

In testing meters on loads of low power factors, suitable reactances can be substituted for the ordinary lamp bank (arc lamp reactances can sometimes be conveniently used for this purpose), or the potential windings of the meter may be excited from a different phase of a three-phase system from that which is supplying the load; in this case the power factor will be 50 per cent, and may be either lagging or leading, depending upon which phase is used for exciting the potential winding. In lagging the meter for low power factors, a two-phase system may be used, exciting the potential winding from one phase and furnishing current from the other, in which case the disc should remain stationary with full load current flowing.

In order to determine which phase of a three-phase system to use for exciting the potential windings to get a lagging power factor, and which phase to use in order to get leading power factor, simply connect a small reactance coil in the place of the lamp bank (if such a load is employed), and then connect the potential winding of the meter first to one phase and then to the other. The meter will run slower on the phase giving a lagging power factor.

Where a great number of watthour meters of the same type are to be tested (such as is the case with large distributing companies in testing new meters), the testing stand shown in Fig. 97 permits of very rapid work, since a meter can be hung in place and connections made within three or four seconds. The stand consists of a wooden base about 2 x 1½ ft., upon which is mounted another vertical 2-in. board of about the same dimensions. Fig. 97 shows the elevation and plan views. Three "L-shaped" terminals are brought out through the vertical board, the spiral springs being used to press the terminals firmly against the binding screws of the meter's connection block.

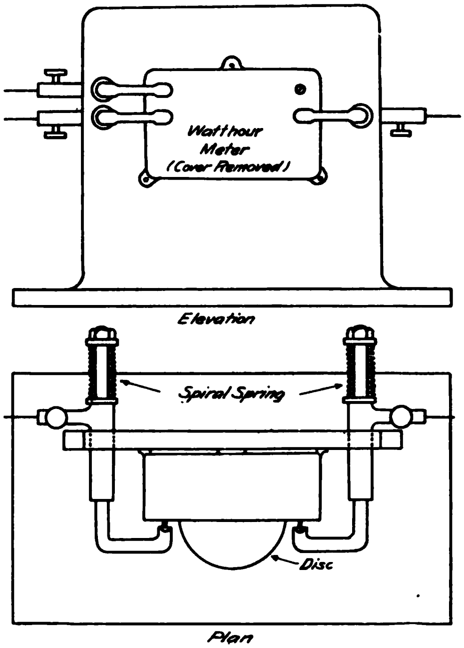


Fig. 97.

Another method, employing a connection board essentially the same as shown in Fig. 96, is shown diagrammatically in Fig. 98. Instead of using a lamp bank for loading the watthour meter in test, a "phantom load" transformer, T, is used, the secondary of

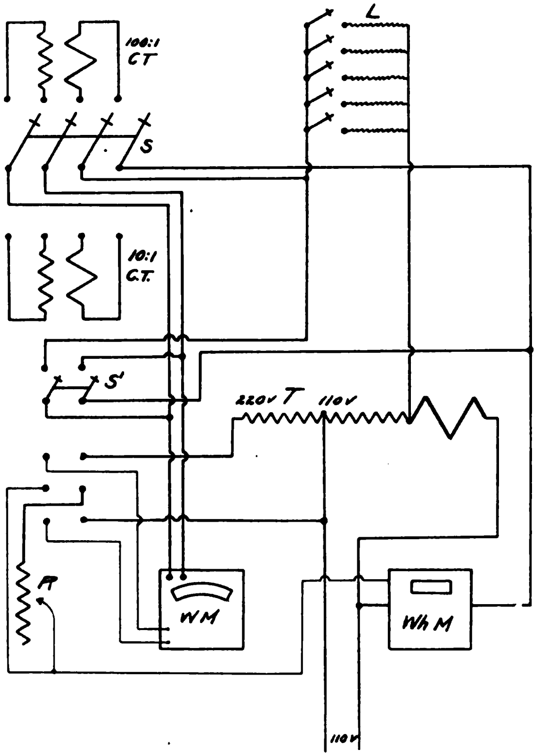


Fig. 98.

which is capable of supplying a heavy current at a very low potential, thereby necessitating only the small resistance coils, L, for regulating the load. This method requires only a small amount of power even in the case of large meters, and is therefore very economical.

Testing Polyphase Meters.

In testing polyphase watthour meters, it is usually most convenient to adjust and test them on a single-phase circuit as simple single-phase meters; a polyphase meter so tested will then be correct for polyphase work. The current coils may be connected in series and the potential coils in multiple for testing as a single-phase meter; when tested in this way the constant of the meter should be divided by two, since the current is passing through both elements and is consequently being registered twice. A balanced reading should be taken on both elements as follows:

Potential should be put on both elements and a load put on the current coil of one element, the number of revolutions which the disc makes in a given time being noted; the current coil of this element should then be disconnected and that of the other element connected in the same manner with the same load applied for the same length of time, the revolutions of the disc again being noted. The revolutions of the disc in each instance should be exactly the same, and if any variation is found, the element whose speed is incorrect should be adjusted as described in Chap. III.

A better method of testing polyphase meters is to apply polyphase potential to the potential windings exactly as will be the case when the meter is in service. With such connections, a load is placed on one element and the meter tested as though it were a single phase meter, using the disc constant as stamped on the disc (divided by the ratio of the current transformers times the ratio of the potential transformers). The load should then be taken off of this element and the other loaded, by means of which a "balanced" reading can be obtained, proper adjustments being made if the elements do not balance. The advantage of testing the meter with polyphase potential applied to the potential windings is that the interference of the potential winding of one element with that of the other will be normal, and can be compensated for to great extent in the calibration of the meter.

A three-phase, four-wire meter can be tested exactly the same as a three-phase, three-wire meter by using the two current windings which are wound one on each element, leaving the third current winding open-circuited. The third winding is wound on both elements and when such a meter is tested on single-phase current with both potential coils connected in multiple the meter will run at double speed when this winding is carrying the load.

Polyphase meters should always be calibrated for 50 per cent power factor as well as for unity power factor, since they are almost always used upon circuits which at times operate under low power factor conditions.

Meters Used With Current and Potential Transformers

When watthour meters are used in connection with "current," or "series," transformers, there are two possible sources of error which may ensue; one being due to the angular displacement between the primary and secondary currents of the transformer (this displacement should be exactly 180 degrees), and the other is due to the varying ratio of the transformer at various loads. The first of these two sources of error is negligible except in the case of low power factors, and is largely compensated for by the angular displacement introduced by the potential transformer, as will be explained later in this chapter.

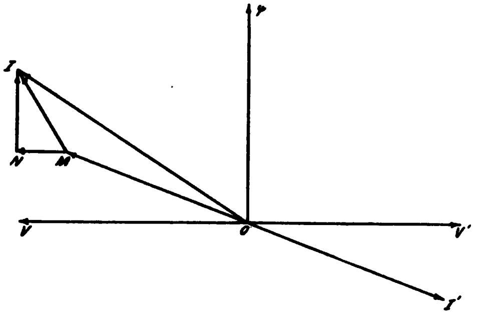


Fig. 99.

Fig. 99 is a vector diagram showing the phase relations of the currents in the primary and secondary of a current transformer; IM is a component of the primary, or line current which acts as exciting current for the transformer and is responsible for both errors above mentioned. In the figure,

OI = the primary or line current,
OI^1 = the secondary current,
Oϕ = the magnetic flux in the transformer core,
OV = the voltage of primary winding,
OV^1= the voltage of the secondary winding,
IN = the magnetizing current,
NM= the **energy** component which supplies the losses of the transformer and the load.

One source of error is due to the fact that OI is not exactly 180 degrees displaced from OI^1, and therefore the current which flows through the meter (from the secondary side), will not have the proper phase relation with respect to the current in the potential coils of the meter. As already stated, however, for all practical purposes the error thus introduced is negligible except in the case of low power factors, and in transformers of poor design. It can be seen by referring to the above diagram that if the secondary circuit has the proper amount of inductance to cause the secondary current OI^1 to lag by the same angle that the exciting current, IM, lags, that the secondary current will be exactly 180 degrees out of phase with the primary current, which would result in there being no error from this cause.

The second error referred to, which is caused by the varying ratio of the transformer, is due to the exciting current, IM, not being effective in inducing current in the secondary winding; the secondary current being induced by the component, OM, of the primary current. If IM varied directly as the primary current, this error could be corrected by adjusting the ratio between the primary and secondary turns; such is not the case, however, and an error is introduced.

Fig. 100 is a curve showing the accuracy of a well-designed current transformer. In calibrating watthour meters for use in connection with current transformers, the meter should be calibrated to register correctly on the flat part of the curve. There will then be a slight error at either end of the curve, that is, there will be an error on very light loads on or overloads, but if the meter is carefully calibrated in accordance with the curve of the transformer it will be accurate over the greater part of the range, and the error at either extreme will be small.

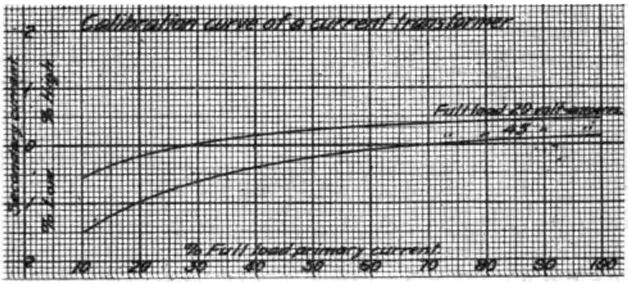


Fig. 100.

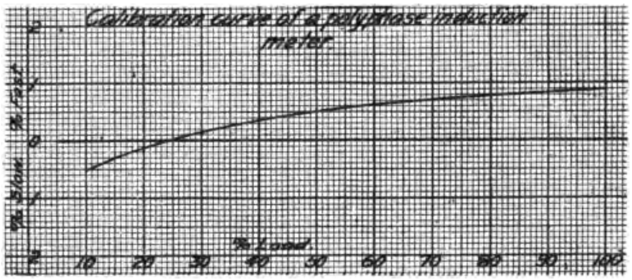


Fig. 101.

Fig. 100 shows a typical calibration curve of a good current transformer, and Fig. 101 shows the calibration curve of a standard induction watthour meter. These two curves are combined as shown in Fig. 102, the resultant curve, B, being the resultant calibration curve of the meter when used in connection with the transformer. It will be seen that if the meter is adjusted so that it will be a little slow on full load (about 0.5 per cent), and if the light load adjustment is set so that the meter will be slightly fast (about 0.5 per cent) on 10 per cent load, the resultant curve will be more nearly correct, and when a high degree of accuracy is required, this is recommended, the amount of such adjustment being determined by referring to the calibration curve of the transformer with which the meter is to be used.

It should be remembered that a current transformer must always have a load on its secondary side; if the meter or instrument with which it is being used should be disconnected while current is still on the primary, the transformer should either be disconnected from the line, or else have its secondary short-circuited. If the secondary is left open-circuited there will be no counter magneto-motive force from the secondary, consequently the magnetic flux will increase to such a degree that it will cause the iron core to become overheated to an extent that may injure the transformer.

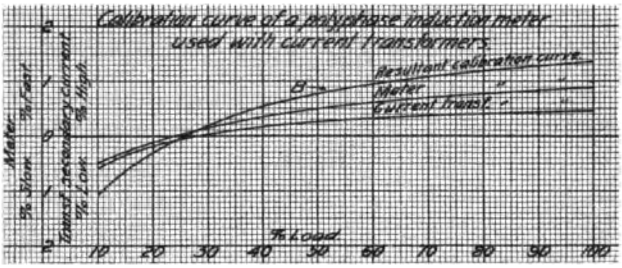


Fig. 102.

The load carried by potential transformers is constant, and if the load is light, the error in the transformer ratio will be very small. The secondary e.m.f. of the potential transformer leads the primary e.m.f. by a small angle, θ, Fig. 103; the angular displacement referred to in connection with current transformers is also leading; it therefore follows that the angular displacement in a potential transformer compensates, in a large degree, for the angular displacement in the current transformer; if this angular displacement is the same for both the current and potential transformers the error from this source will be entirely eliminated from the meter with which they are used.

The angular displacement referred to depends upon the magnitude and character of the load imposed upon the transformer, as well as upon its design.

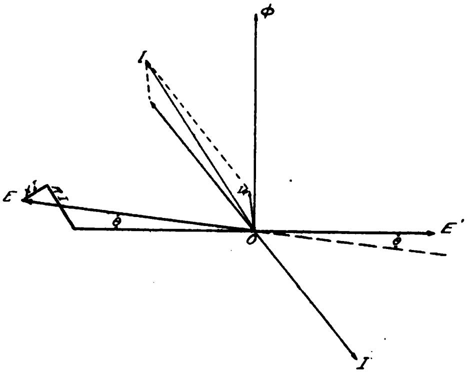


Fig. 103.

Fig. 103 shows a vector diagram of the regulation of a potential transformer, in which

OE=primary e.m.f.,
OE'=secondary e.m.f.,
OI=primary current,
OI'=secondary current,
RI=total resistance drop,
XI=total reactance drop,
θ=angular displacement between primary and secondary e.m.f.'s.

In using 5-ampere 110-volt meters with current and potential transformers and leaving the regular register on the meter it is necessary to use a multiplying constant, which, multiplied by the register reading, gives the kilowatt hours consumed. This multiplying constant is obtained by multiplying the ratio of the current transformer by the ratio of the potential transformer.

In order to obtain a multiplying constant of 10, 100 or 1,000 it is often necessary to use a special register and to change the disc constant of the meter. The new disc constant is obtained from the following formula:

$$K = \frac{100 \text{ x register ratio x transformer ratio}}{10{,}000 \text{ x } C}$$

in which C is the multiplier of 10, 100 or 1,000.

Applying the above formula to an example we will take the case of a 5-ampere meter having a disc constant of K=.3, and used with a 20 : 1 ratio potential transformer and a 24 : 1 ratio current transformer, from which the "transformer ratio" in the formula will be (20 x 24)=480 : 1. Suppose a register is chosen having a ratio of 66 2-3, and a multiplier (C) of 100 is used. Substituting these values in the above formula we derive a value of K=.312, which should be used instead of K=.3, which would of course result in a slightly different operating speed of the disc.

Meter Troubles

Some of the most common troubles encountered in connection with watthour meters may be summarized as follows:

Excessive Vibration—If a meter is placed in such a position as to be subject to excessive vibration, creeping often results; vibration is also severe on the lower bearing. This trouble can in many cases be remedied by placing rubber washers between the meter and the wall upon which it is supported; in severe cases a spring suspended board is recommended. Wherever possible, meters should be installed in places that are entirely free from vibration or jarring effects. It is not unusual to find meters installed near doors which are often closed and opened, and especially is this bad practice where the wall or partition is of light construction.

Humming and Rattling of Induction Meters—This trouble is usually due to loose laminations in the magnetic circuit, and can be remedied by tightening them up. Rattling may also be due to a vibration of the disc and shaft in very loosely aligned meters, which trouble can usually be removed by carefully examining, locating and tightening the exact parts that may be loose. Excessive humming is sometimes caused by the potential winding being loose on the potential pole, which trouble can be easily remedied by driving small, flat wooden wedges between the insulating sleeve (upon which the coil is mounted) and the core.

Humming is not an inherent phenomenon of the induction meter, and trouble from this source can always be traced to some simple mechanical defect. It sometimes happens that the wall upon which the meter is mounted acts as a "sounding board," thus magnifying the humming of the meter. This can be corrected by the use of rubber washers as above mentioned for excessive vibration. It is best, however, to remove the meter to a place that will not be subject to such trouble.

Weakening of the Retarding Magnets—Magnets, after having been in service for some time, may become weak, due to the "aging" of the steel; this should not occur, however, if they have been thoroughly and properly treated before leaving the factory. Weakening due to aging is a very serious defect and shows the lack of proper methods or care in their manufacture. Such trouble should be guarded against in the selection of meters. The retarding magnets may also be weakened by the effects of powerful stray fields, or by heavy short circuits on the "load" side of the meter.

The retarding magnets should never be moved closer than one-quarter of an inch to the periphery of the disc, because if they are there will be a leakage of magnetic flux around the disc, from pole to pole of the magnets, thereby decreasing the number of lines of force that actually cut the disc. This of course will have the same effect as the weakening of the magnets, and will cause the meter to run fast. Magnets that will not produce the necessary retarding effect when moved within a quarter of an inch of the edge of the disc are too weak and they should be discarded.

Sometimes it is found necessary to place iron shields around the damping system of meters which are not already provided with such a protection against stray fields, and when this is done the meter should be re-calibrated, since the proximity of the iron shield may allow a leakage of flux which would result in the same trouble as placing the magnets too near the periphery of the disc.

Bent Shafts and Buckled Discs—These troubles may be due to one of three causes; by abuse, by the effects of short circuits of a severe nature, or to faulty manufacture; the only remedy is to install new parts.

Creeping—Creeping may be due to "over-compensation" of the light load adjustment, vibration, high voltage, or a combination of any or all of these effects, or in commutating meters by the external resistance being short-circuited. Some types of induction meters have two small holes punched in their discs, the holes being diametrically opposite. When the part of the disc which has the hole in it comes under the influence of the electrical element, the torque is thereby sufficiently decreased to allow the disc to stand in that position when there is no current flowing in the series coils. This method very effectually prevents "creeping," but it does not affect the accuracy of the meter.

Creeping in the commutating type of meter can be very effectively eliminated by clamping over the edge of the disc a small piece of U-shaped soft iron wire; when the piece of wire comes under the influence of the retarding magnet the attraction of the magnet tends to hold the disc in that particular position, therefore preventing creeping on no load. The size of the clip can be so selected that it will prevent creeping, but which will not prevent the meter from starting on light loads nor affect the light load accuracy.

A modification of the last named method consists in attaching a piece of iron wire to the shaft of the meter in such a manner that its free end extends out radially and comes under the influence of the retarding magnets; the effect of the wire can be varied by bending it so that its free end comes closer to or further from the magnets.

Defective Jewels—The simplest and probably the easiest way of detecting roughness or defectiveness in the jewel bearing is to take the point of a sharp needle and gently "feel" the entire surface of the jewel. A fracture or any roughness can thus be detected. In this connection it might be stated that one of the best materials for cleaning the jewels and pivots is the pith from a cornstalk. After the jewel and pivot have been thoroughly cleaned, the pivot should be wiped with a clean rag which has been moistened with a high grade of watch oil, but under no conditions should it be flooded with oil.

Changing Position of Commutator on Shaft—If the commutator is shifted from its correct position on the shaft it will cause the meter to run slow; if it is shifted 90 degrees the meter will stop, and if shifted more than 90 degrees the meter will run backward.

Backward Rotation of Commutating Meters on Light Load—It may sometimes be found that the commutator meter will run in a reverse direction on light loads, while on heavier loads it will run in the proper direction. Such a trouble will be found due to a reversed connection of the compensating field, so that instead of helping the main field out, its action is differential. Care should therefore be taken to see that the compensating field is properly connected.

Open-Circuited Armatures—The current in entering the commutator divides at each brush and flows through the armature in two multiple paths of equal resistance; if one of these paths is opened, it will therefore be seen that the equivalent resistance of the armature will be doubled, which will cause the meter to run at about half speed. The same result may be accomplished by using an ordinary 16 candle-power lamp and moving the connection from one bar to the other; the lamp will not light until after the defective coil has been passed.

The defective coil can very easily be located with a voltmeter. Apply the normal voltage to the two brushes and with one of the voltmeter leads permanently attached to one brush, move the other lead over the commutator from bar to bar, during which operation no deflection will be indicated on the voltmeter until the defective coil is reached, unless the movable voltmeter terminal happens to be passed over that half of the armature in which there are no open-circuits.

Friction in Upper Bearing—It sometimes happens that the upper bearing is pressed down too tightly against the upper end of the shaft, thereby causing excessive friction which will result in the meter running slow on light loads; this trouble is easily remedied by loosening the binding screw and raising the bearing slightly.

Friction in the Registering Mechanism—If the registering mechanism is allowed to accumulate dirt and grease it will develop undue friction; care should therefore be taken to see that the registers are kept in good, clean condition.

Dirt on Meter Disc—Small pieces of trash or dirt on the meter disc will, if they come in contact with the retarding magnets, or the stationary element, act as a brake on the meter.

CHAPTER VIII.

RATES.

The fixing of a scale of rates for the sale of electrical energy which will be fair to both the consumer and the distributing company is a difficult problem, which will here be briefly outlined. We will confine ourselves to showing why it is that electrical energy cannot be sold to all classes of consumers at the same rate, and further to reproduce schedules of rates as adopted by some of the leading distributing companies throughout the United States.

Electrical energy cannot be stored in large quantities except at a great expense, but must ordinarily be "manufactured" as the demand necessitates. For this reason, it is necessary for the distributing company to provide generating and distributing equipment to handle the maximum demand or "peak load," and since the peak load usually lasts for only a few hours, the system is being operated for the greater part of the day at a production much below its full capacity. The operating expenses, however (except fuel, etc.), remain practically the same, as do the fixed charges, the maintenance, depreciation and interest on the investment. The charges which are proportional to the quantity of energy being generated, such as water, fuel, etc., constitute the smaller portion of the total cost, therefore it is evident that the distributing company can sell electrical energy to consumers using it for a good many hours per day cheaper than it can to consumers using it for only a few hours per day, since the revenue from the "long hours" customer will be greater even at a lower rate, while the manufacturing expense will not be much greater.

To illustrate the above statements take as an example two consumers, each taking the same amount of power, but one of which takes this power for ten hours per day while the other takes it for two hours per day. The equipment necessary to supply each customer is practically the same, as are also the fixed charges. A profit of one cent per kilowatt-hour above operating expenses from the customer taking power for ten hours per day would be more profitable to the distributing company than would a profit of two or three cents per kilowatt-hour from the customer taking power for only two hours. In the first case the gross profit above operating expenses would be ten cents per kilowatt per day, while in the second case it would be four or six cents. Suppose that the fixed charges amounted to 4 cents per kilowatt per day, the two hour customer would yield a profit of only two cents per kilowatt demand per day, while the ten hour customer, at a rate of 2 cents lower, would yield a profit of 6 cents per kilowatt demand per day, or three times as much. In the case of very small consumers, the cost of bookkeeping, meter reading, testing, etc., is disproportionately high; the losses in the distributing system are also out of proportion, which further increases the cost of supplying energy to the small consumer.

The distributing company can afford to sell energy during the "off-peak" period cheaper than it can during the hours of the peak load, since during the period of maximum demand, the equipment is usually taxed to its utmost. An increase in the peak load means an increase in the equipment or else a greater strain and depreciation on the present installation, while an increase in the "off-peak" load can be readily handled with the resulting increase in revenue. Generating and distributing equipment has to be provided of sufficient capacity to take care of the peak load. During off-peak hours, a large part of this equipment is idle. The charges (maintenance, depreciation and interest on the investment) due to this excess equipment provided to handle the peak load are properly chargeable to the cost of manufacture during peak load hours, which makes the cost of producing a kilowatt-hour during this time high.

Since the cost of manufacture is higher during the peak load, it is only fair and just that the consumers demanding current at this time should pay a correspondingly higher rate.

Another point which should be borne in mind when determining the rates made to different customers is the nature of the load with regard to the power factor. The capacity of the generating and distributing equipment is limited by the amount of current to be handled, from which it is evident that the cost of supplying energy to a load of low power factor will be higher than the cost of supplying a similar load (in kilowatts) of a higher power factor. Especially is this true during the period of maximum demand.

REPRESENTATIVE SCHEDULES OF RATES.

The Commonwealth Edison Co., of Chicago, Ill.

Schedule A.—Regular Lighting Rate.

The following is the regular rate for electricity for lighting purposes, or upon an interior distributing circuit carrying electricity for lighting and also for heating or power through the same meter, as measured by a meter or meters owned and installed by the company:

Thirteen cents (13c) per kilowatt hour for all electricity consumed in each month up to and including an amount that would be equal to thirty hours' use of the consumer's maximum demand in such month, and seven cents (7c) per kilowatt hour for all electricity consumed in such month in excess of that amount.

Maximum recording meters will be installed by the company for the purpose of ascertaining the maximum demand, except where the capacity of the consumer's installation is less than one kilowatt, in which case the maximum demand will be estimated.

A discount of one cent per kilowatt hour on the consumer's total monthly consumption will be allowed on monthly bills paid on or before ten days after their respective dates.

The rate stated in this schedule A covers and includes, for incandescent lighting, the free installation and use of the proper supply of incandescent lamps of the company's present standard carbon filament types, and of the same voltage,

efficiency and candlepower as the incandescent lamps now furnished by the company.

An abatement or reduction of one-half cent ($\frac{1}{2}$c.) per kilowatt-hour from the aforesaid rate shall be allowed to a consumer furnishing, maintaining and renewing all the lamps or other forms of electric illuminants used by him.

Schedule B.—Regular Power Rate.

The following is the regular rate for electricity used for power purposes exclusively, as measured by a meter or meters owned and installed by the company:

> Eleven cents (11c) per kilowatt hour for all electricity consumed in each month up to and including an amount that would be equal to thirty hours' use of the consumer's maximum demand in such month; and six cents (6c) per kilowatt hour for all electricity consumed in such month in excess of that amount.

When the electricity is taken from the company's direct current system, the greatest number of kilowatts used at one time (the peak of the load) in any month shall be deemed the maximum demand for such month; and maximum recording meters will be furnished by the company for the purpose of ascertaining the maximum demand, except where the capacity of the consumer's installation is less than one kilowatt, in which case the maximum demand will be estimated.

When the electricity is taken from the company's alternating current system, the maximum demand for any month shall be the number of kilowatts equal to a percentage of the total kilowatt capacity represented by all motors connected, which percentage shall be in accordance with the following table of percentages:

Where installations are under 10 horsepower, and only one motor is used	85%
Where installations are under 10 horsepower, and more than one motor is used	75%
Where installations are from 10 horsepower to 50 horsepower, both inclusive (irrespective of number of motors)	65%
Where installations are over 50 horsepower (irrespective of number of motors)	55%

The horsepower capacity of any alternating current motor or motors shall be assumed to be that which is indicated by the manufacturer's standard nominal rating or ratings; and each horsepower shall be deemed to be equal to seven hundred and forty-six watts. The company shall, however, have the right ,from time to time, to test any such motor or motors, and if it be found on any such test that the actual horsepower used by such motor or motors exceeds its or their rated capacity, the kilowatt equivalent of the maximum horsepower actually used shall constitute the consumer's maximum demand.

A discount of one cent (1c.) per kilowatt-hour on the consumer's total monthly consumption will be allowed on monthly bills paid on or before ten days after their respective dates.

The consumer shall pay to the company each month not less than fifty cents (50c.) per horsepower, or fraction thereof, in rated capacity of motor or motors connected.

Schedule C.—Wholesale Rates for Electricity.

Any consumer entering into a written contract to use the company's electricity for either lighting or power, or both, for a period of not less than five years in any single premises occupied by him, will, at his option, be given a wholesale rate for such premises, in lieu of the rates stated in Schedules A and D, which wholesale rate shall consist of both a primary and a secondary charge in accordance with the following specification of charges:

Direct Current.—Contract Without Guaranty.

Primary Charges.

For Each Month:

$3.20 per kilowatt of the consumer's maximum demand in such month up to and including 20 kilowatts.

$2.50 per kilowatt of the excess of the consumer's maximum demand in such month over 20 and up to and including 50 kilowatts.

$2.20 per kilowatt of the excess of the consumer's maximum demand in such month over 50 kilowatts.

Secondary Charges.

For Each Month:

6c per kilowatt-hour for the consumption in such month up to and including 2000 kilowatt hours.

3c per kilowatt-hour for the excess consumption in such month over 2000 and up to and including 5000 kilowatt hours.

1.4c per kilowatt-hour for the excess consumption in such month over 5000 kilowatt-hours.

Contract with Guaranty.

If the consumer will guarantee that his maximum demand in each year of the contract term shall be not less than 200 kilowatts, the following primary and secondary charges will be made:

Primary Charges.

$28.00 per kilowatt per year reckoned upon 200 kilowatts, the guaranteed maximum demand; and

$25.00 per kilowatt per year for the excess, if any, over 200 kilowatts of the consumer's actual maximum demand recorded in the year.

Such primary charges for each year to be paid by the consumer in installments as follows:

At the end of each month he shall pay $2.33 1-3 per kilowatt reckoned upon 200 kilowatts, and $2.08 1-3 per kilowatt for the excess, if any, over 200 kilowatts of the maximum demand recorded in the year previously to that time.

At the end of the year he shall pay the difference, if any, between the sum of the prescribed monthly installments for the year, and the amount constituting the full primary charge for the year.

Secondary Charges.

For Each Month:

6c per kilowatt-hour for consumption in such month up to and including 2000 kilowatt-hours.

3c per kilowatt-hour for the excess consumption in such month over 2000 and up to and including 5000 kilowatt-hours.

1.4c per kilowatt-hour for the excess consumption in such month over 5000 kilowatt-hours.

Alternating Current Transformed.—Contract Without Guaranty.

Primary Charges.

For Each Month:

$3.20 per kilowatt of the consumer's maximum demand in such month up to and including 20 kilowatts.

$2.20 per kilowatt of the excess of the consumer's maximum demand in such month over 20 and up to and including 50 kilowatts.

$2.00 per kilowatt of the excess of the consumer's maximum demand in such month over 50 kilowatts

Secondary Charges.

For Each Month:

6c per kilowatt-hour for the consumption in such month up to and including 2000 kilowatt-hours.

3c per kilowatt-hour for the excess consumption in such month over 2000 and up to and including 5000 kilowatt-hours.

1.1c per kilowatt-hour for the excess consumption in such month over 5000 and up to and including 30,000 kilowatt-hours.

.9c per kilowatt-hour for the excess consumption in such month over 30,000 kilowatt-hours.

Contract With Guaranty.

If the consumer will guarantee that his maximum demand in each year of the contract term shall be not less than 200 kilowatts, the following primary and secondary charges will be made:

Primary Charges.

$26.00 per kilowatt per year reckoned upon 200 kilowatts, the guaranteed maximum demand; and

$21.50 per kilowatt per year for the excess, if any, over 200 kilowatts of the consumer's actual maximum demand recorded in the year.

Such primary charges for each year to be paid by the consumer in installments as follows:

At the end of each month he shall pay $2.16 2-3 per kilowatt reckoned upon 200 kilowatts, and $1.75 1-6 per kilowatt for the excess, if any, over 200 kilowatts of the maximum demand recorded in the year previously to that time.

At the end of the year he shall pay the difference, if any, between the sum of the prescribed monthly installments for the year, and the amount constituting the full primary charge for the year.

Secondary Charges.

For Each Month:

6c per kilowatt for the consumption in such month up to and including 2000 kilowatt-hours.

3c per kilowatt-hour for the excess consumption in such month over 2000 and up to and including 5000 kilowatt-hours.

1.1c per kilowatt-hour for the excess consumption in such month over 5000 and up to and including 30,000 kilowatt-hours.

.9c per kilowatt-hour for the excess consumption in such month over 30,000 kilowatt hours.

Alternating Current Untransformed.—Contract With Guaranty.

If the consumer will guarantee that his maximum demand in each year of the contract term shall be not less than 200 kilowatts, the following primary and secondary charges will be made:

Primary Charges.

$25.00 per kilowatt per year reckoned upon 200 kilowatts, the guaranteed maximum demand; and

$20.50 per kilowatt per year for the excess, if any, over 200 kilowatts of the consumer's actual maximum demand recorded in the year.

Such primary charges for each year to be paid by the consumer in installments as follows:

At the end of each month he shall pay $2.08 1-3 per kilowatt reckoned upon 200 kilowatts, and $1.70 5-6 per kilowatt for the excess, if any, over 200 kilowatts of the maximum demand recorded in the year previously to that time.

At the end of the year he shall pay the difference, if any, between the sum of the prescribed monthly installments for the year, and the amount constituting the full primary charge for the year.

Secondary Charges.

For Each Month:

6c per kilowatt-hour for the consumption in such month up to and including 2000 kilowatt-hours.

2.7c per kilowatt-hour for the excess consumption in such month over 2000 and up to and including 5000 kilowatt-hours.

1c per kilowatt-hour for the excess consumption in such month over 5000 and up to and including 30,000 kilowatt hours.

.8c per kilowatt-hour for the excess consumption in such month over 30,000 kilowatt-hours.

Bills for both primary and secondary charges will be rendered monthly and a discount of ten per cent. (10%) upon the secondary charges will be allowed on all bills paid on or before ten days after their respective dates.

Schedule U.—Automobile Charging in Private Garages.

The rate for electricity for charging automobiles in private garages is either the regular power rate specified in Schedule B, or the power rate under contract for one year or longer specified in Schedule D as the consumer may prefer, subject, however, to the following additional provisions:

The net minimum charge to be paid by the consumer each month shall be not less than sixty-six and two-thirds cents (66 2-3c) for each kilowatt of the consumer's maximum demand in such month, and no monthly bill shall be less than one dollar and fifty cents ($1.50). Where alternating current charging boards are used no monthly bill shall be less than one dollar and fifty cents ($1.50) for each charging board.

Schedule V.—Automobile Charging in Public Garages.

The rate for electricity for charging automobiles in public garages is either the regular power rate specified in Schedule B, or the power rate under contract for one year or longer, specified in Schedule D, as the consumer may prefer, subject, however, to the following additional privisions:

If the consumer agrees not to make use of the company's service for this purpose during the two hours of the day between four and six o'clock P. M., his net rate for electricity furnished for charging automobiles shall not exceed five cents (5c.) per kilowatt-hour.

Where alternating current charging boards are used no monthly bill shall be less than one dollar and fifty cents ($1.50) for each charging board.

Schedule W.—Rates for "Throw-Over" Switch Service.

Where a consumer's premises are supplied with electricity either for light or power, or both, from some plant in the building in which the premises are situated (whether such plant belongs to the consumer or not), and such consumer desires to be in a position to use, or in fact uses, the company's electrical service, not regularly but only occasionally and during the temporary break-down or cessation of such plant; or where a consumer's premises are supplied with power of any kind from any plant in the building in which the premises are situated (whether such plant be an electric plant or not, or be owned by the consumer or not), and such consumer desires to be in a position to use, or in fact uses, the company's electrical power service, not regularly but only occasionally and during the temporary bread-down or cessation of such plant, the consumer will be charged and must pay to the company for such emergency service the rate hereinafter in this schedule provided, to-wit:

Such rate will be that specified in Schedule A. D. or E, according to the purpose for which the service is used, with the additional requirement that the consumer shall pay, irrespective of the amount of his consumption, a minimum monthly charge depending upon the number and capacity of lamps, motors and other apparatus arranged for connection with the company's service, which charge shall be in accordance with the following table of minimum charges:

For each incandescent lamp so connected, ten cents (10c) per month where the lamp has a capacity of fifty (50) watts or less, at rated voltage, and at the rate of ten cents (10c) per month for fifty (50) watts of capacity where the lamp has a capacity exceeding fifty (50) watts.

For each arc lamp so connected one dollar ($1.00) per month where the lamp has a capacity of five hundred (500) watts or less, at rated voltage, and at the rate of one dollar ($1.00) per month for five hundred (500) watts of capacity where the lamp has a capacity exceeding five hundred (500) watts.

For each motor so connected, other than a motor used for operating elevators, hoists or similar machinery, one dollar and fifty cents ($1.50) per month per rated horsepower of such motor.

For each motor so connected used for operating elevators, hoists or similar machinery, five dollars ($5.00) per month per rated horsepower of such motor.

The company will furnish emergency service under this schedule only when the premises are situated on its existing lines having the requisite capacity, and only when the consumer signs a contract for the service, running for one year or longer and specifying the number and capacity of lamps, motors or other electrical apparatus in his premises that are to be supplied with the company's electricity during such occasional periods and providing that the consumer shall so arrange his wiring that no lamps, motors or apparatus other than those specified in the contract can be thrown on the company's service by means of switches, or otherwise. For the purpose of this service the company will enter its service main into the building in which the consumer's premises are situated (providing the consumer, in case he shall not own the building, shall obtain the necessary consent from the owner), and the consumer must, at his own expense, install switches and such other equipment as may be necessary for connecting his premises with such service main at the point of entry into the building. For service under this schedule the company will not furnish lamps or renewals for the same.

The Edison Electric Illuminating Co., of Boston, Mass.

Lighting Rates—Commercial.

Electricity for any use will be sold, under the following schedule, to any customer who has signed an agreement for electric service, embodying the terms and conditions of the company.

A price of 12 cents per kilowatt-hour will be charged for all electricity furnished under this schedule, and the minimum charge will be $1.00 per month per meter.

Power Rates—Commercial.

Electricity for power use will be sold, under the following schedule, to any consumer who has signed an agreement for electric service, embodying the terms and conditions of the company. "Power" is defined as general motor service, cooking, heating, electroplating, charging storage batteries, and similar service, but does not include the running of dynamos for electric lighting purposes.

A price of 12 cents per kilowatt-hour will be charged for all electricity furnished under this schedule, with the following deductions, and the minimum charge will be $1.00 per month per meter:—

A price of 9 cents per kilowatt-hour will be charged for all electricity furnished in excess of 23 and not exceeding 103 hours' use of the *demand for each month.

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*The demand is the greatest amount of electricity used by the customer at any one time. Until such time as the company installs one or more indicators, automatically to determine the demand, either in whole or in part, it may estimate the demand. The demand on any circuit, when an indicator is installed, will be the average of the regular monthly readings of the indicator, between October 1st and the following February 1st in each year. The demand so determined, beginning February 1st of each year, shall be the demand for the next twelve months, except that the demand in no case shall be less than 1/3 of the highest reading during the previous twelve months and in no case shall be less than one kilowatt; and provided that if any direct-connected elevator (as defined by the company) be installed the demand shall not be taken at less than 10 kilowatts. The customer has the privilege of having the indicator cut out one night in each month, provided a 48-hour written notice is given to the company.

A price of 6 cents per kilowatt-hour will be charged for all electricity furnished in excess of 103 hours' use of the demand for each month.

Whenever that portion of a customer's bill which is calculated at the 9-cent and 6-cent rate, or both, exceeds $10.00 per month, a discount of 70 per cent will be allowed on such excess over $10.00.

Whenever a customer's bill, after the foregoing deductions have been made, exceeds $100.00 per month, a discount of 30 per cent will be allowed on all in excess of $100.00.

Elevator Rates—Commercial.

Electricity for direct connected elevator use will be sold, under the following schedule, to any customer who has signed an agreement for electric service, embodying the terms and conditions of the company. A "direct-connected' elevator is defined as being an elevator running in guides, and in which the car starts at the same time as the motor.

A price of 12 cents per kilowatt-hour will be charged for all electricity furnished under this schedule, with the following deductions, and the minimum charge will be $1.00 per month per meter:—

A price of 5 cents per kilowatt-hour will be charged for all electricity furnished in excess of 300 kilowatt-hours and not exceeding 600 kilowatt-hours per month.

A price of 3 cents per kilowatt-hour will be charged for all electricity furnished in excess of 600 kilowatt-hours and not exceeding 4000 kilowatt-hours per month.

A price of 2½ cents per kilowatt-hour will be charged for all electricity furnished in excess of 4000 kilowatt-hours per month.

Yearly Lighting Rates—Commercial.

Electricity for any use will be sold, under the following schedule, to any customer who has signed an agreement for yearly electric service, embodying the terms and conditions of the company.

A price of $60.00 per year, payable in equal monthly installments will be charged per kilowatt of the *demand up to and including 15 kilowatts.

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*The demand is the greatest amount of electricity used by the customer at any one time. Until such time as the company installs one or more indicators, automatically to determine the demand, either in whole or in part, it may estimate the demand, but in no case shall it be taken at less than 2/10 of a kilowatt. The demand on any circuit, when an indicator is installed, will be the greatest reading of the indicator between November 1st and the following February 1st of each year, and the demand so determined, beginning February 1st of each year, shall be the demand called for by the agreemnt for the next twelve months, except that the demand in no case shall be less than 1/3 of the highest reading during the previous twelve months. The customer has the privilege of having the indicator cut out one night in each month, provided a 48-hour written notice is given to the company.

A price of $36.00 per year, payable in equal monthly installments, will be charged per kilowatt of the demand for all kilowatts exceeding 15 and up to and including 55.

A price of $30.00 per year, payable in equal monthly installments, will be charged per kilowatt of the demand for all kilowatts exceeding 55.

These prices do not include the supply of electricity.

A price of 5 cents per kilowatt hour will be charged for all electricity furnished under this agreement up to and including 1500 kilowatt-hours per month.

A price of 3 cents per kilowatt-hour will be charged for all electricity furnished under this agreement exceeding 1500 kilowatt-hours and up to and including 5500 kilowatt-hours per month.

A price of 2½ cents per kilowatt-hour will be charged for all electricity furnished under this agreement exceeding 5500 kilowatt-hours per month.

Permanent Electric Rates.

Electricity for any use in specified premises will be sold, under the following schedule, to any customer who has signed an agreement for at least 50 kilowatts of permanent electric service, embodying the terms and conditions of the company.

A price of $60.00 per year, payable in equal monthly installments, will be charged per kilowatt of service up to and including 15 kilowatts.

A price of $36.00 per year, payable in equal monthly installments, will be charged per kilowatt of service for all kilowatts exceeding 15 and up to and including 55.

A price of $30.00 per year, payable in equal monthly installments, will be charged per kilowatt of service for all kilowatts exceeding 55.

These prices do not include the supply of electricity.

A price of 5 cents per kilowatt-hour will be charged for all electricity furnished under this agreement up to and including 1500 kilowatt-hours per month.

A price of 3 cents per kilowatt-hour will be charged for all electricity furnished under this agreement exceeding 1500 kilowatt-hours and up to and including 5500 kilowatt-hours per month.

A price of 1½ cents per kilowatt-hour will be charged for all electricity furnished under this agreement exceeding 5500 kilowatt-hours and up to and including 105,500 kilowatt-hours per month.

A price of 1¼ cents per kilowatt-hour will be charged for all electricity furnished under this agreement exceeding 105,500 kilowatt-hours per month.

The company will deliver its electricity at the customer's premises, and, in consideration of not supplying lamps and care, will deduct from the net amount of the bill, as otherwise rendered, ½ cent per kilowatt-hour.

The company will provide capacity for intermittent overloads up to 40 per cent in excess of the kilowatts applied for by the customer.

An excess price of 20 cents per kilowatt hour will be charged for all electricity furnished at any time in excess of the kilowatts applied for by the customer.

Terms and Conditions.

For the purpose of determining the amount of electricity used, a meter shall be installed by the company upon the customer's premises at a point most convenient for the company's service, upon the reading of which meter all bills shall be calculated. If more than one meter is installed, unless for the company's convenience, each meter shall be considered by itself in calculating the amount of the bill. When more than one meter or discount indicator is installed under this agreement, for the company's convenience, the sums of the consumptions and demands shall, in all cases, be taken as the total consumption and demand.

All bills shall be due and payable upon presentation and shall be rendered monthly, unless either the customer or the company desires bills rendered weekly, in which case it may be done by adjusting to a weekly basis all the monthly figures referred to in the schedule of rates.

A minimum charge will be made of $1.00 per month per meter, unless otherwise provided.

The customer will be responsible for all charges for electricity furnished under this agreement until the end of the term thereof and for such further time as he may continue to take the service; except that where the customer has the right to terminate the agreement by notice, which shall be in writing, he shall remain liable for all charges for ten days thereafter.

The customer will be responsible for all damage to, or loss of, the company's property located upon his premises unless occasioned by the company's negligence.

The company shall not be responsible for any failure to supply electricity, or for interruption or reversal of the supply, if such failure, interruption or reversal is without default or neglect on its part.

The company reserves the right to install a circuit breaker, so arranged as to disconnect the service in the premises, if the company's capacity at that point is exceeded.

If a customer, who is not paying a rate calling for an annual fixed cost, desires to use the electric service as auxiliary to another source of power (excluding, however, small sources of power not exceeding two horsepower) he may do so only by paying a minimum charge of $3.00 per month per kilowatt for as many kilowatts as it is possible for him to use on the service at any one time; this number to be determined by a circuit breaker, so arranged as to disconnect the service if the number of kilowatts is exceeded.

If lamps and care are supplied under this agreement, they will be supplied only for such installation as uses the company's electricity exclusively.

It is agreed that all lamps, plugs, meters and such other appliances as are furnished by the company shall remain its property. And it is further agreed that all wiring upon the premises of the customer, to which the company's service is to be connected, shall be so installed that the company may carry out this contract, and shall be kept in proper condition by the customer.

Permission is given the Company to enter the customer's premises, at all times, for the purpose of inspecting and keeping in repair or removing any or all of its apparatus used in connection with the supply of electricity, and for said purpose the customer hereby authorizes and requests his landlord, if any, to permit said company to enter said premises.

The benefits and obligations of this contract shall inure to and be binding upon the successors and assigns, survivors and executors or administrators (as the case may be) of the original parties hereto, respectively, for the full term of this contract.

Birmingham (Alabama) Railway, Light & Power Co.

The consumer hereby agrees to pay the company, monthly, within ten days after presentation of bills, for said incandescent light service at the base rate of twelve cents per kilowatt hour, as measured by meter or meters to be furnished and installed by the company, subject to the following discounts:

LIGHTING RATES.

On monthly	bills	under		25	k.w.h.	10 %
"	"	"	over	25	"	15 %
"	"	"	"	150	"	20 %
"	"	"	"	250	"	25 %
"	"	"	"	400	"	30 %
"	"	"	"	500	"	35 %
"	"	"	"	1,000	"	37½%
"	"	"	"	1,500	"	40 %
"	"	"	"	2,000	"	42½%
"	"	"	"	2,500	"	45 %
"	"	"	"	3,000	"	47½%
"	"	"	"	3,500	"	50 %

The consumer agrees to pay the company a net minimum monthly bill of ($........) ....Dollars as a readiness to serve charge.

POWER RATES.

Discount for Monthly Usage.

500—1000	k.w.h.	per	month	10%	discount
1000—2000	"	"	"	12%	"
2000—3000	"	"	"	14%	"
3000—4000	"	"	"	16%	"
4000—5000	"	"	"	18%	"
Over 5000	"	"	"	20%	"

In addition—

10 to 15	k.w.h.	used	per	h.p.	installed	4%	discount
15 — 20	"	"	"	"	"	6%	"
20 — 25	"	"	"	"	"	8%	"
25 — 30	"	"	"	"	"	10%	"
30 — 35	"	"	"	"	"	12%	"
35 — 40	"	"	"	"	"	14%	"
40 — 45	"	"	"	"	"	16%	"
45 — 50	"	"	"	"	"	18%	"
50 — 55	"	"	"	"	"	20%	"
55 — 60	"	"	"	"	"	22%	"
60 — 65	"	"	"	"	"	24%	"
65 — 70	"	"	"	"	"	26%	"
70 — 75	"	"	"	"	"	28%	"
75 — 80	"	"	"	"	"	30%	"
80 — 85	"	"	"	"	"	32%	"
85 — 90	"	"	"	"	"	34%	"
90 — 95	"	"	"	"	"	36%	"
95 — 100	"	"	"	"	"	38%	"
Over 100	"	"	"	"	"	40%	"

10% additional for off peak service.

The San Francisco Gas & Electric Co., of San Francisco, Cal.

Lighting Rates.

All current delivered to the consumer shall be registered by a meter or meters installed and owned by the Company and the rate and minimum charge shall be as follows per meter:

per k.w.h.		k.w.h.
8	cents if the monthly consumption be less than	79
7	“ “ “ “ from	80— 129
6½	“ “ “ “ “ “	130— 189
6	“ “ “ “ “ “	190— 244
5¾	“ “ “ “ “ “	245— 309
5½	“ “ “ “ “ “	310— 374
5¼	“ “ “ “ “ “	375— 449
5	“ “ “ “	450— 548
4¾	“ “ “ “ “ “	550— 674
4½	“ “ “ “ “ “	675— 849
4¼	“ “ “ “ “ “	850—1099
4	“ “ “ “ “ “	1100 or over

The consumer agrees to pay the company a net monthly minimum bill of $1.00 for each meter installed, provided the bill for current consumed at the above premises, does not equal or exceed the said sum of $1.00 per month.

The consumer further agrees to pay a minimum of $1.50 per month, for each horsepower in motor or motors installed, provided the bill for current consumed does not equal or exceed the said sum of $1.50 per horsepower per month.

Power Rates.

All current delivered to the Consumer shall be registered by a meter or meters installed and owned by the Company and the rate and minimum charge shall be as follows per meter:

Per 1000	If the monthly consumption
9 cents	is above the minimum and { less than 2,000 w.h. per 16 c.p. lamp.
8.55 “	shall be from 2,000 to 3,000 w.h. per 16 c.p. lamp.
8.1 “	“ “ “ 3,000 to 4,000 “ “ “ “ “
7.65 “	“ “ “ 4,000 to 5,000 “ “ “ “ “
7.2 “	“ “ “ 5,000 to 6,000 “ “ “ “ “
6.75 “	“ “ “ 6,000 to 7,000 “ “ “ “ “
6.3 “	“ “ “ 7,000 to 8,000 “ “ “ “ “
5.85 “	“ “ “ 8,000 to 9,000 “ “ “ “ “
5.4 “	“ “ “ 9,000 or over “ “ “ “ “

Per k.w.h.	If the monthly consumption
5.25 cents	shall be from 375 to 649 k.w.h.
5 “	“ “ “ 650 to 924 “
4.75 “	“ “ “ 925 to 1,199 “
4.50 “	“ “ “ 1,200 to 1,474 “
4.25 “	“ “ “ 1,475 to 1,749 “
4 “	“ “ “ 1,750 or over “

The consumer agrees to pay to the company a net monthly minimum bill of $1.00 for each meter installed, provided the bill for current consumed at the above premises does not equal or exceed the said sum of $1.00 per month.

The consumer further agrees to pay a minimum of $1.50 per month, for each horsepower or fraction thereof in motor or motors installed, provided the bill for current consumed does not equal or exceed the said sum of $1.50 per horsepower or fraction thereof per month.

From the data given above, a very good general idea can be gained of the fixing and application of lighting and power rates throughout the United States, though of course local conditions may cause a wide variation from the figures given.

APPENDIX.

Definitions.

In many respects electric circuits closely resemble a water system, in which the pressure is analogous to the voltage of the electric circuit and the quantity (in cubic feet per second) to the current flowing in the wires. This comparison will often aid in the solution of various electrical problems.

Definitions.

Ampere=the unit of electrical current, and is that current which will deposit silver at the rate of 0.001118 grams per second when flowing through an electrolytic solution of silver nitrate.

Ohm=the unit of resistance, and is equivalent to the resistance of a column of pure mercury, at 0° centigrade, 103.6 centimeters high, of uniform cross section, and weighing 14.4521 grams.

Volt=the unit of electrical pressure (electromotive-force), and is that pressure which will maintain the flow of one ampere of current against the resistance of one ohm.

Let R=the resistance of a given circuit, E the voltage impressed and I, the current in amperes, then for direct current,

$$E = R \times I \text{ (Ohm's Law)},$$

which is the fundamental equation of direct current circuits.

Watt=the unit of electrical power; the watts equal the product of the volts and the amperes in direct current circuits, and to the product of the volts, the amperes and the power factor in alternating current circuits. (See Chap. II.)

Kilowatt=one thousand watts.

Watthour=the unit of electrical **energy**, and is equivalent to the flow of one watt for one hour.

Kilowatt-hour=one thousand watthours.

Inductance: The inductance of an electrical circuit is the property of that circuit whereby it can convert electric energy into magnetic energy, and vice versa. Inductance bears a close resemblance to "inertia" in mechanics, and has been called "electrical inertia." Inertia is that property of a moving body whereby it resists any change in its velocity; if a rapidly moving body is suddenly stopped, as, for example, a hammer striking a nail, a great force is exerted by the body against the obstacle which brings it to rest; the magnitude of the force depending upon the suddenness with which the moving body is stopped and upon the inertia of the body. In an electric circuit containing inductance, if the current is suddenly interrupted, a high e.m.f. is produced which tends to cause the current to continue. The magnitude of this "induced" e.m.f. depends upon the suddenness with which the current is interrupted and upon the inductance of the circuit. The inertia of any given body is proportional to its mass; the energy stored in a moving body is $W = \frac{1}{2} MV^2$, where M is the mass (= weight divided by the gravitational constant), and where V is the velocity. The magnetic energy stored in an electric circuit due to its current and inductance is $W = \frac{1}{2} LI^2$, where L is the inductance and I is the current.

Henry=unit of inductance; a circuit having an inductance of one henry will have an e.m.f. of one volt induced in it by a current changing at the rate of one ampere per second.

Milli-henry=0.001 henry.

Power Factor=the ratio of **true** watts to **apparent** watts (see Chap. II).

Cycle—one complete wave or alternation of current or e.m.f. (See Fig. —, Chap. II.)

Frequency=number of cycles per second.

Impedance=the **vector** sum of the resistance and the reactance of an electric circuit and is expressed by the following equation:

$$Z = \sqrt{R^2 + X^2},$$

in which R is the resistance in ohms, and X is the reactance ($= 2\pi f \times L$, where f is the frequency in cycles per second and L is the inductance in henrys). The voltage drop in an alternating current circuit containing both reactance and resistance is

$$E = Z \times I,$$

where Z is the impedance as above expressed and I is the current in amperes.

Determination of Temperature Rise by Resistance Method.

In testing electrical machinery such as generators, motors and transformers, it is impossible to obtain the internal temperature of the windings by use of thermometers; the following formula will therefore be useful in determining the **average** temperature of such windings:

$$\text{Rise in temperature} = (238 + t)\left(\frac{F}{R} - 1\right)\text{degrees C,}$$

in which 238 is a constant; R is the initial resistance of the winding at a room temperature, t, and F is the final resistance. If the room temperature differs from 25° C, the calculated temperature should be corrected by ½% for each degree C. Thus with a room temperature of 15°, the rise in temperature should be increased by 5%, or if the room temperature is 35°, the rise in temperature as calculated should be decreased by 5%, etc.

Adjusting Meters for Use With Current and Potential Transformers.

The usual method of testing watthour meters used with current and potential transformers is to test and adjust the meters without the transformers, taking into consideration, of course, the ratio of the transformers. Where a great degree of accuracy is not required, this procedure will answer very well; but where, as with large consumers, a small percentage error represents a considerable sum of money, the errors introduced by the current and potential transformers should be taken into account and, as far as may be, compensated.

The errors introduced by the current and potential transformers are (1) errors in ratio of the transformers and (2) errors due to improper phase relations between the primary and secondary currents and e.m.f's.

The errors due to ratio can be easily compensated by adjusting the meter in accordance with the ratio curves of the transformers at unity power fatcor. The ratio of the potential transformer will remain constant as its load is constant. The ratio of the current transformer will not remain constant, but will vary with the load. It tends to make the meter fast at full load and slow at light load. This can be compensated by adjusting the meter to be a little slow at full load and fast at light load.

The errors due to improper phase relations between the primary and secondary currents and e.m.f.'s are of more serious nature and more difficult to eliminate than errors due to ratio. The errors from this source are negligible at unity power factor, but may be considerable at low power factors, depending on the design of the transformers.

The diagram, Fig. 1, shown below, is a vector diagram of a current transformer. OI is the primary or

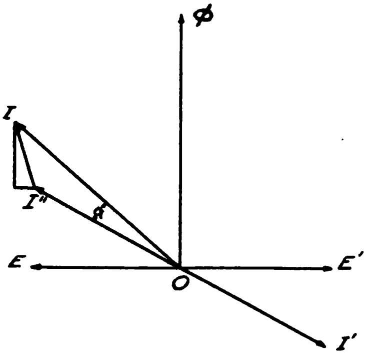

Fig. 1.

line current, OI′ is the secondary current and lags behind OE′, the secondary e.m.f. of the current transformer, by an angle depending on the power factor of the secondary load (meter coils and leads). II″ is the exciting current, the magnetizing component of which is at right angles to and the energy component in phase with the primary e.m.f., OE, of the current transformer. OI″ is that component of the primary current inducing a current in the secondary, or is the secondary referred back to the primary. It will be seen that OI′ leads OI by and angle *a* which will tend to make the meter run fast on inductive loads.

Fig. 2 is the vector diagram of a potential transformer. OE is the primary e.m.f. OE′ is the secondary e.m.f. OI is the primary current, OI′ the secondary

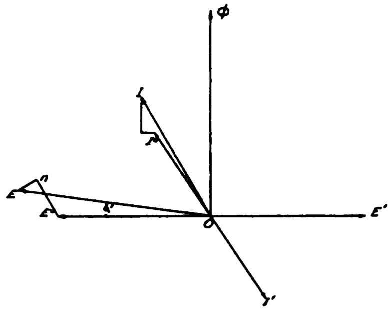

Fig. 2.

current and II′ the exciting current. E″N is the e.m.f. consumed by resistance or is the RI drop, EN the e.m.f. consumed by the reactance or is the XI drop, and EE′ is the impedance e.m.f. of the transformer. In the figure it will be seen that the secondary e.m.f. (OE″ referred to the primary) leads the primary e.m.f by an angle *a*′. This will tend to make the meter run slow on inductive loads.

Obviously, if *a* of the current transformer equals *a*′ of the potential transformer there will be no error from this source, and it is attempted in the design of meter transformers to approximate this condition. For this reason considerable resistance is introduced into the potential transformer to increase this angle. This high resistance results in a transformer of poor regulation, but the regulation is not important, as the load is constant and the range recommended narrow.

In practice, the angle α of the current transformer is greater than the angle α' of the potential transformer. This difference can be compensated in the lag of the meter. Suppose, for example, the meter is not lagged properly by the angle ω. Then, if $\alpha - \alpha' - \omega = O$ there will be no error from this source. In other words, the meter is lagged so that it will run slow on inductive loads. The combined effect of angular displacement in the potential transformer and of the meter not being lagged quite ninety degrees just compensates for the angular displacement of the current transformer.

These angles may be determined and corrections made as follows: The results obtained by this method are sufficiently accurate for adjusting service meters since finer corrections could not be made on the meters themselves.

With an indicating wattmeter the power flowing in a circuit of 50 per cent power factor (or other known power factor) is read. A one to one ratio current transformer of the type used with the watthour meters is then inserted in the circuit and the current for the watt-meter is taken from the secondary of the current transformer. The power is again read. Assuming that a power factor of 50 per cent is used, from the first reading we get $W = EI \cos 60^\circ$ and from the second reading $W' = EI \cos (60 - \alpha)$. The angle α is the angular displacement due to the current transformer. From the above

$$\text{Cos } (60 - \alpha) = \frac{W' \cos 60^\circ}{W}$$

From which we can readily obtain α. Before substituting in the formula W' should be corrected for error in transformer ratio. The current coils of the watt-meter are again connected directly in circuit and the potential supplied by potential transformers, two transformers being used, one to step up from the line voltage and the other to step down again to the watt-meter. We can now obtain the angular displacement due to the potential transformers by applying the same formula as given above for current transformers. The angle thus obtained for the potential transformers will be twice the angle of one transformer, and as it is the angle of one transformer with which we are concerned the result obtained should be divided by two. This will give us the angle a'. We will then lag the meter, not for 90°, but for $90^\circ - (a - a')$.

Another and quicker way of applying this method is to determine the error introduced by two potential transformers at unity and at 50 per cent power factor. Each transformer is responsible for ½ of the error. Now connect the watthour meter in circuit with the current transformer and with two potential transformers, one potential transformer, stepping up from the line voltage (testing circuit) and the other stepping down to the watthour meter. The indicating watt-meter should be connected directly in the circuit without current or potential transformers. The watthour-meter is than adjusted at unity power factor and at 50 per cent power factor to disagree with the indicating watt-meter by the amount of the error due to one potential transformer. There will be errors due to three transformers, one current and two potential. The watthour-meter is to operate with but two transformers and should be adjusted to compensate for the errors of only two transformers. By not compensating for the error of one of the potential transformers, as outlined above, the desired results will be accomplished.

It is not strictly correct to take ½ the error of the two potential transformers, as outlined above, as the error of one transformer; it is, however, very close, closer than adjustments can be made on the watthour-meter.

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